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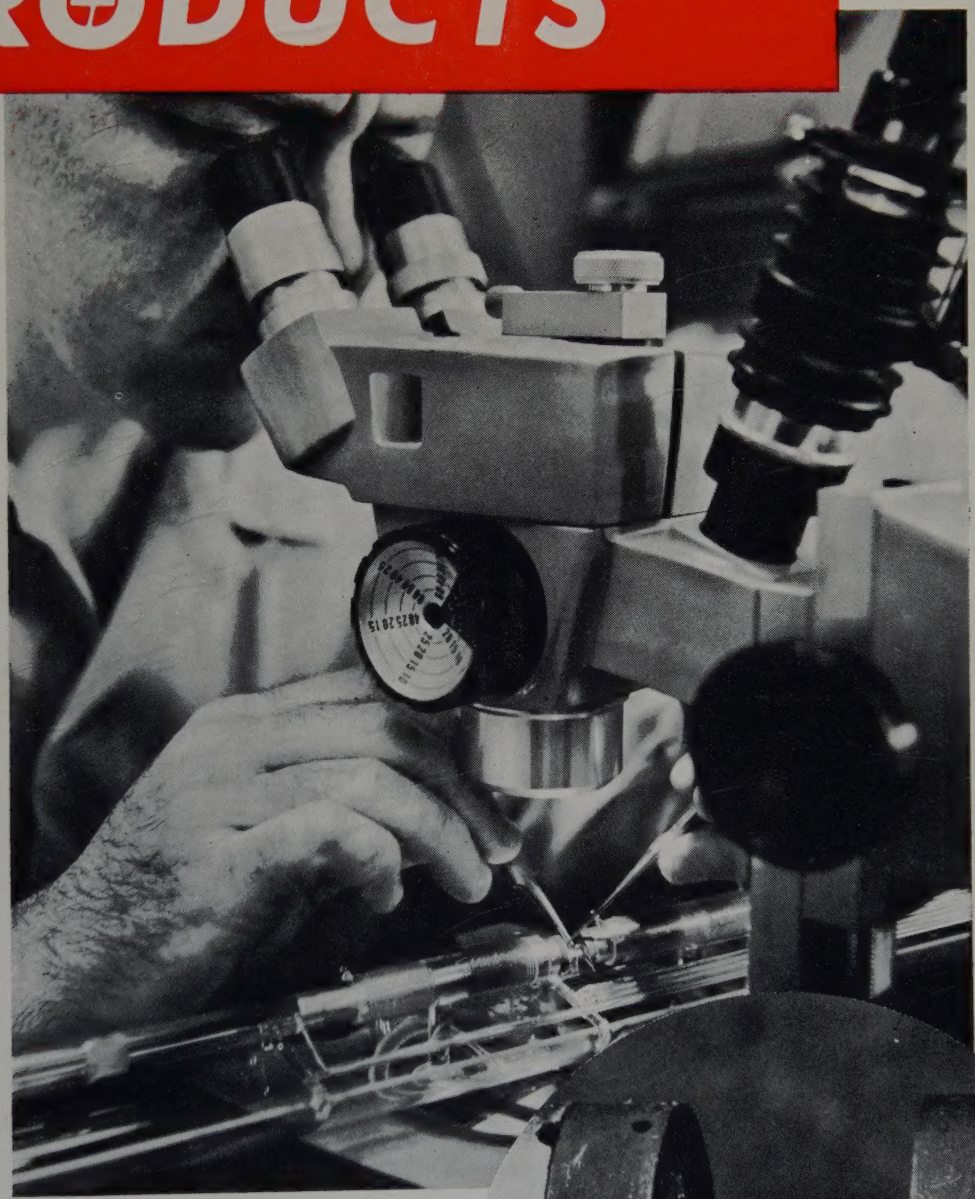

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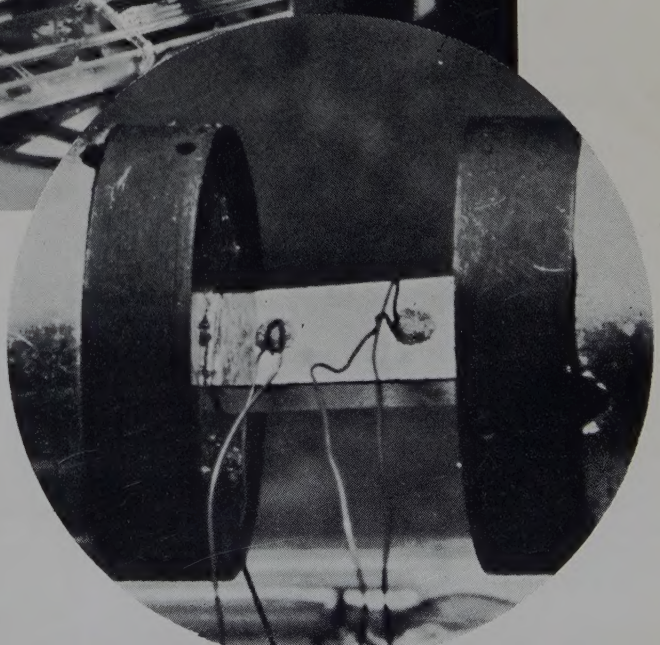

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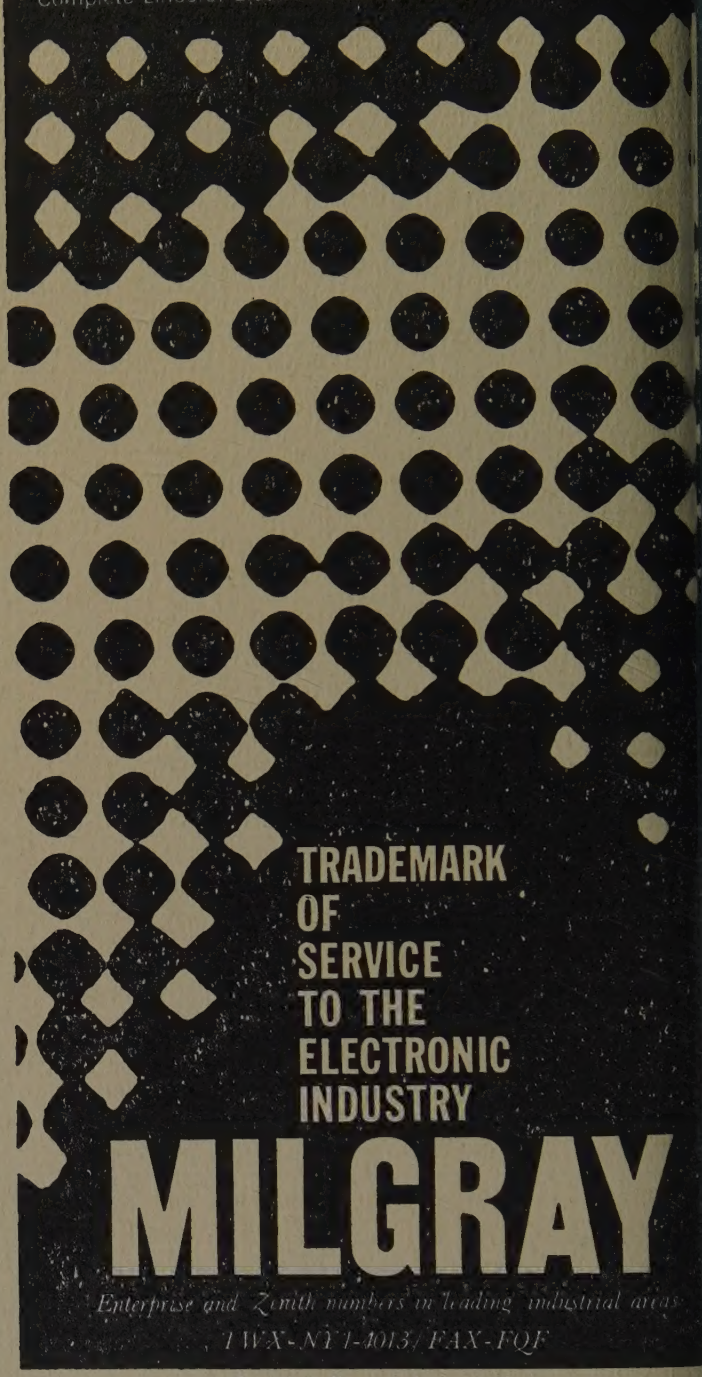

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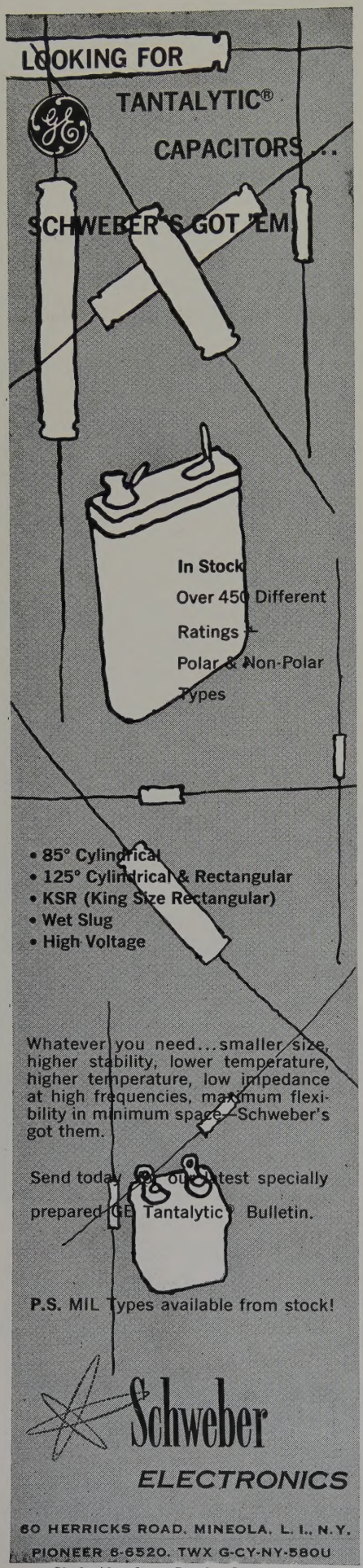
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SEMICONDUCTOR PRODUCTS

SANFORD R. COWAN, Publisher

February 1961 Vol. 4 No. 2

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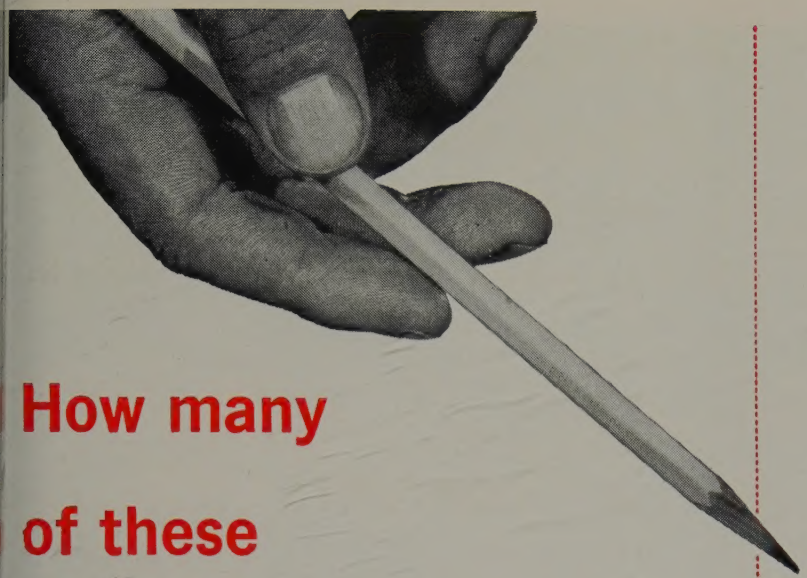
Front Cover

G. Harman of the National Bureau of Standards positions a small platelet of silicon carbide (0.6 x 0.25 x 0.008 cm) mounted between 2 electrical contacts. The specimen is backed with a special glass, which provides mechanical support. Thermocouple leads have been attached to the sample with a gallium-copper alloy developed by the National Bureau of Standards. This alloy is soft at the time of mixing, and resists temperatures to 900° C after hardening. The apparatus shown is designed to measure the thermoelectric power of the specimen.



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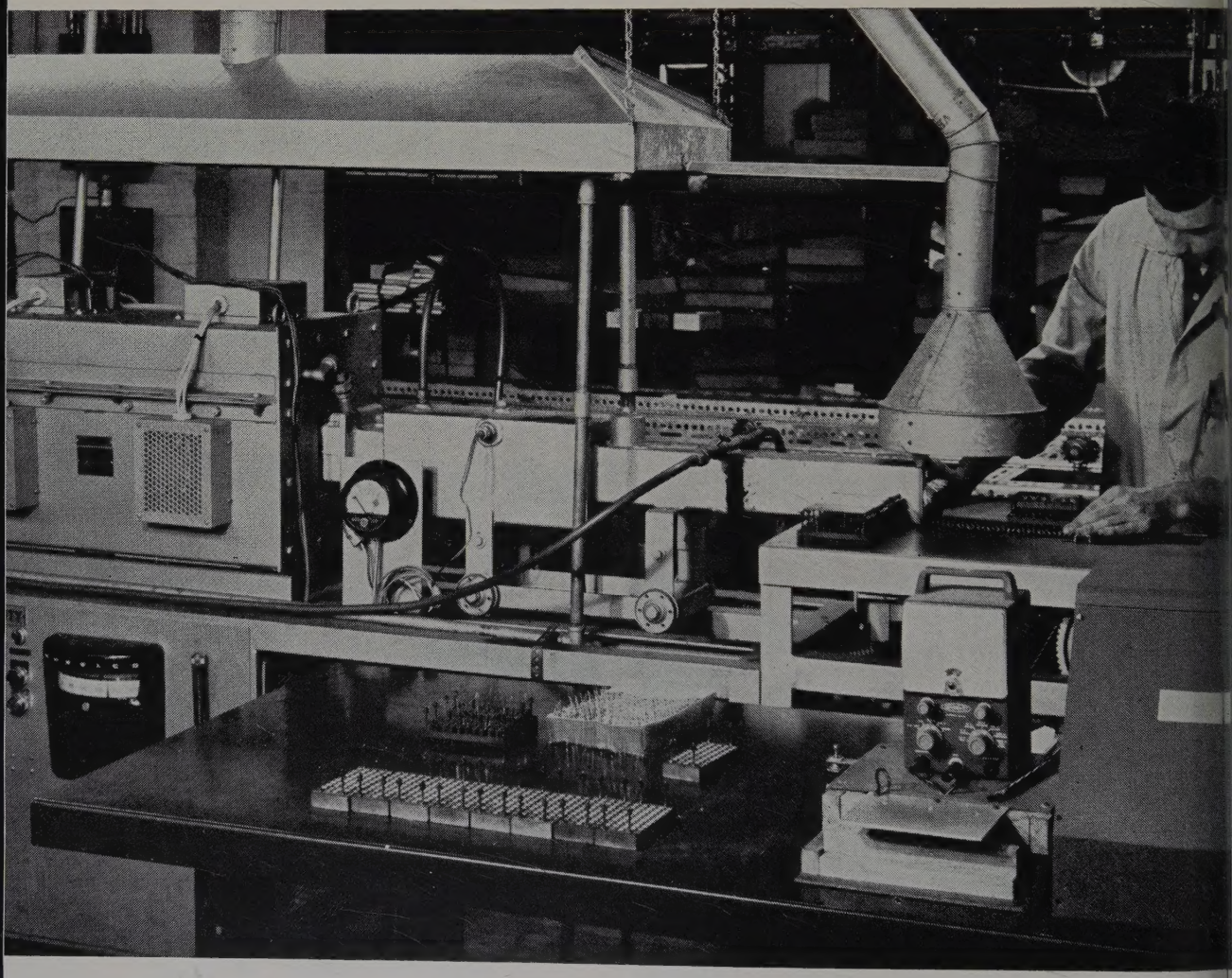

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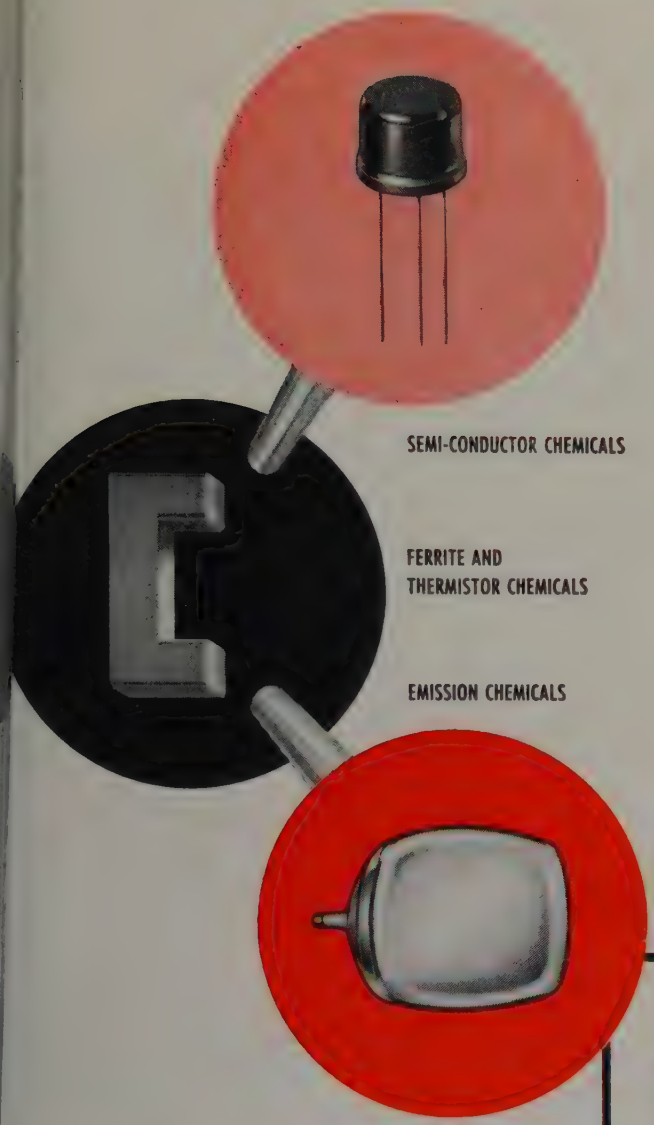

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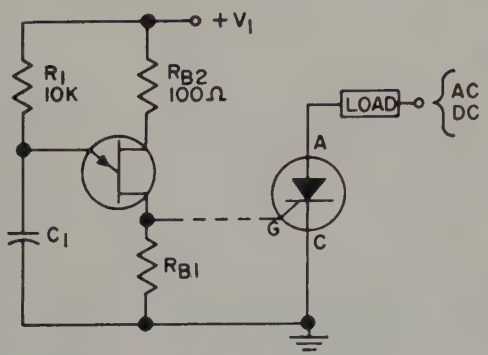

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Transistor Time Delay Circuit	Unijunction Circuit Equivalent
3 transistors*	1 unijunction transistor
1 diode	1 Zener diode
1 Zener diode	1 relay
1 relay	1 capacitor
2 capacitors	4 resistors
8 resistors	

SAVINGS: $3.30 (*germanium transistors)
$16.50 (*silicon transistors)

Transistor Voltage Detector	Unijunction Circuit Equivalent
2 transistors*	1 unijunction transistor
1 potentiometer	1 potentiometer
2 capacitors	1 capacitor
5 resistors	3 resistors

SAVINGS: $0.40 (*germanium transistors)
$9.20 (*silicon transistors)

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	2N1671B	6 μa max.
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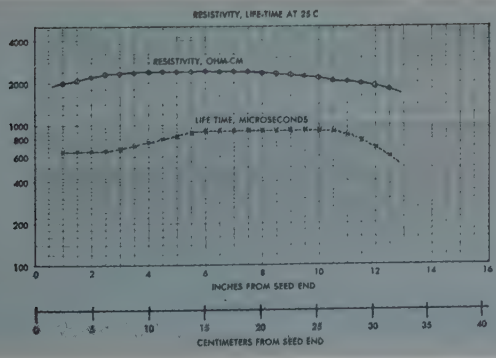

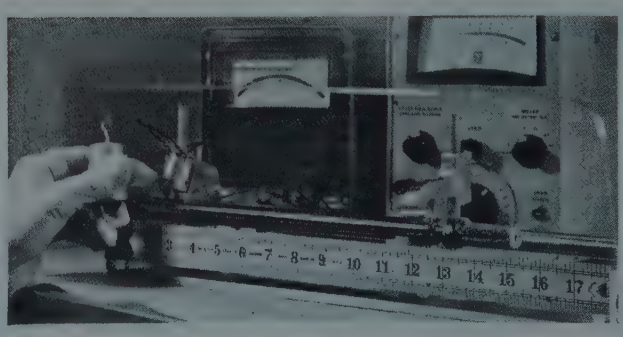

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In case after case, manufacturers who have switched to Alpha preforms of pure aluminum and aluminum alloys, as well as Alpha preforms of other metals and their alloys, report experiences as satisfactory as these.

It's the difference that counts!

What makes Alpha aluminum preforms so unique? *The care with which they are produced.*

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In addition to this purity check, each lot is analyzed by exact quantitative techniques. This safeguards the alloy's homogeneity. It also insures that the minor constituent is present in the precise amount required.

Check and double check

Another indication of the care with which these aluminum preforms are made is the special microscopes Alpha uses to check dimensional accuracy. Spheres as large as ¼" and as small as .003" and discs and washers as thin as .0005" are checked for precise conformation to specifications.

As a further dimensional safeguard, a comparator casting an image 100 times the preform's actual size is used.

To assure freedom from surface contaminants, all Alpha preforms are processed through etching and vapor degreasing equipment. Every scintilla of foreign matter is effectively removed!

Only Alpha has it

Alpha cut segments are produced in pieces as small as .008" dia. x .016" long. Alpha engineers designed and built the machinery to do this; *only Alpha has it!*

Wire of 99.99+% purity is put through this equipment. Not only are the resulting pieces uniformly straight but the ends are cut square and parallel.

Increasing your usable output

These controls would satisfy most preforms suppliers—but not Alpha. Again and again, quality is controlled and checked by skilled technicians using the finest optical and mechanical equipment. The results reflect themselves in preforms of aluminum and other ultra high purity metals that, in case after case, increase the percentage of usable semiconductor devices.

Alpha preforms can help *your* output too. For current quotations on spheres, discs, cylinders, cubes, washers, rings and special shapes, write today. Describe alloys, dimensions and quantities wanted.

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Alphaloy Corp.
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Other Alpha products: Strip with Continuous Conductive Coating, high purity dots of silver indium, cadmium, tin, lead and their alloys in shapes to your needs.

Circle No. 14 on Reader Service Card

Reduce Costly Kerf Losses

in slicing semiconductor material...

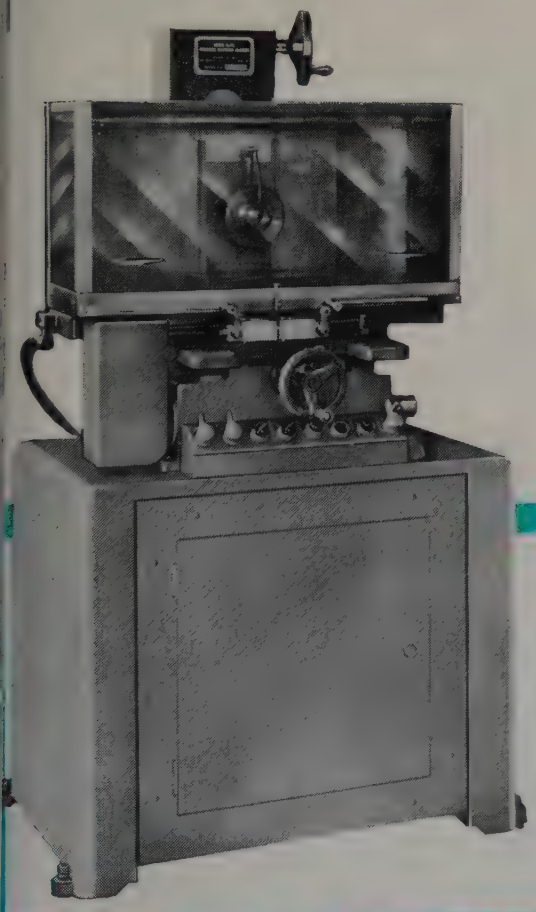
Now... switch to 3½" diameter diamond wheels to slice 1" diameter crystals on

Micromech WAFERING MACHINES

featuring the **NEW TYPE 2**

CARTRIDGE SPINDLE

Micromech's newly-designed Type 2 Cartridge Spindle permits the use of thinner, smaller-diameter diamond wheels for slicing germanium and silicon. Provides top wafering efficiency with wheels of *all* sizes, too!



This specially-engineered spindle mounts a 3½" diamond wheel in place of the usual 5" wheel to give from 40% to 100% more slices per 1" diam. crystal . . . reduce kerf loss by 28% to 47%!

Micromech's 3½" diameter blades—in .010" thickness—can save from .004" to .009" per slice . . . add up to savings of $200.00 a day!

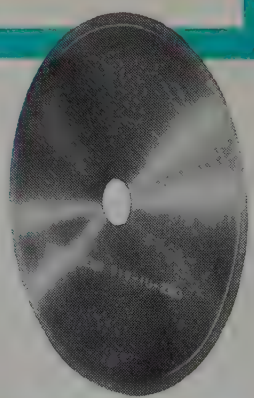
Moreover, the 3½" wheel allows cutting speeds up to 3" per minute . . . increasing production while decreasing loss of material.

Type 2 Cartridge Spindle is now standard on Micromech mechanical and hydraulic automatic wafering machines. Write today for detailed information.

Micromech Diamond Wheels

Micromech stocks 3½" diamond wheels for the economical and fast slicing of all semiconductor materials.

Wheels also available in other popular and odd sizes, DIT and DITRS types. Precision manufacture to close tolerances assures accuracy of cut and long life.



MICROMECH MANUFACTURING CORP.

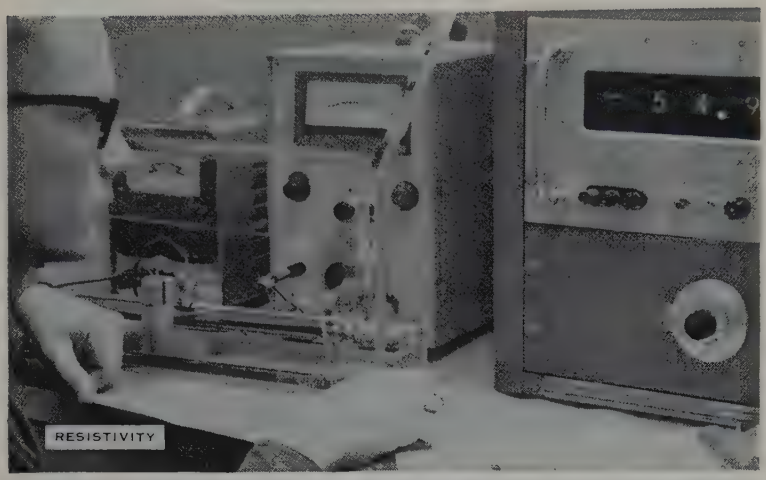
A Division of Sanford Manufacturing Corp.

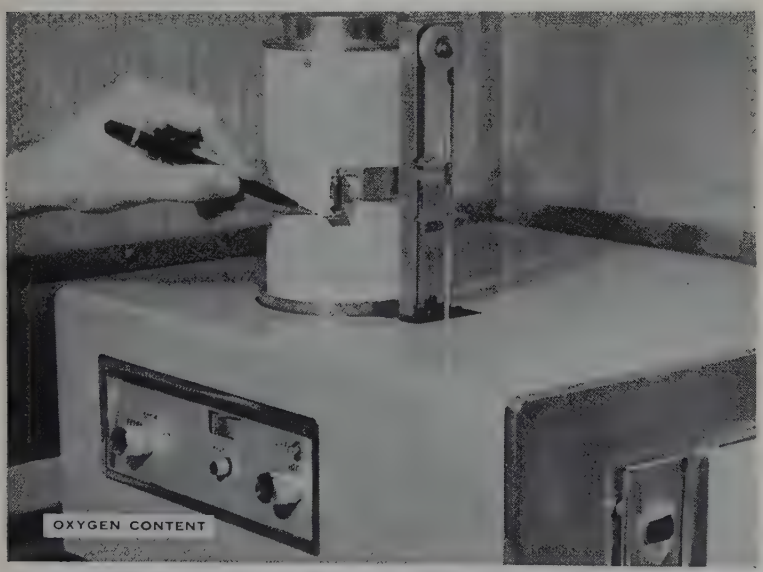
1020 Commerce Avenue Union, New Jersey MUrdock 8-6323

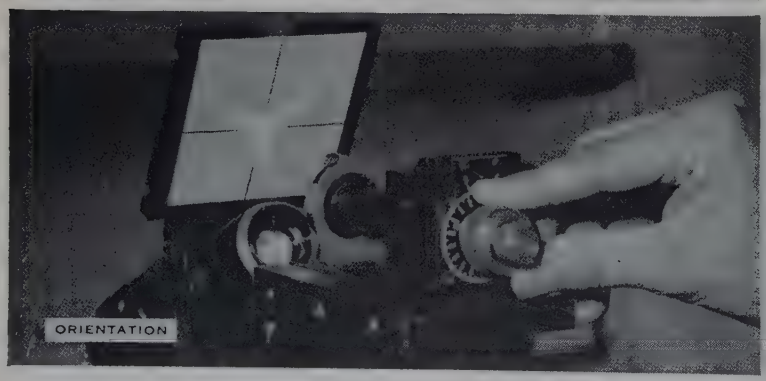
Circle No. 15 on Reader Service Card

The Untouchables (Part 3)

Now...Single Crystal Silicon Doped to Your Specification







Single crystal silicon . . . doped to your specific needs . . . is now available from Dow Corning.

Rigid quality control of Dow Corning Silicon means greater device yield for you! And you achieve uniformity in device characteristics — the result of greater uniformity in characteristics from rod to rod, greater lateral and radial uniformity within each rod.

This high quality is the result of a completely integrated production process — a process that starts with the manufacture of trichlorosilanes and other chemicals basic to silicon production. And at every step of the way, rigid quality control assures the ultimate in quality—purity.

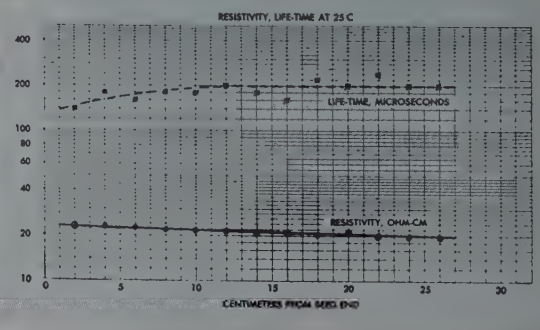
Doped to specification single crystal Dow Corning Silicon contains in the order of 0.1 atoms of minority impurity per billion atoms of P-type material . . . about 0.15 atoms of minority impurity per billion atoms of N-type material.

Low oxygen content of Dow Corning Silicon reduces the undesirable effects on lifetime associated with the diffusion process. Result — few rejects . . . increased device yield! In the picture at left, infrared transmittance at 9 microns is measured to determine oxygen content. Many materials register at pencil point—much higher than Dow Corning Silicon.

Crystal orientation is normally 111, but can be to your specification.

Specify Dow Corning single crystal silicon doped to your requirements. Specific resistivities within narrow tolerances from one to 1000-ohms centimeter P-type . . . one to 400-ohms centimeter N-type. Rod diameters from 3 to 25 mm (1/8″ to 1″) lengths to 250 mm (about 10″).

Whatever your need — polycrystalline rod or chunk; high resistivity P-type single crystal rod; single crystal rod doped to your specifications — Dow Corning should lead your list of sources.



Write for "Hyper-Pure Silicon for Semiconductor Devices." Address Dept. 8214a.

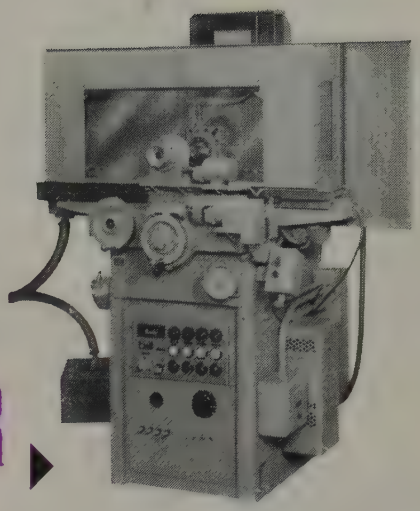
HYPER-PURE SILICON DIVISION
Address: HEMLOCK, MICHIGAN

Dow Corning CORPORATION
MIDLAND, MICHIGAN
ATLANTA BOSTON CHICAGO CLEVELAND DALLAS LOS ANGELES NEW YORK WASHINGTON, D.C.

Circle No. 16 on Reader Service Card

SILICON OR GERMANIUM

ELIMINATE MACHINE VARIABLES WITH THE NEW MODEL 612 SLICER



REID engineers working with technicians from their own electronic controls division have designed and built this machine to answer the need of the semi-conductor industry. The Model 612 Slicer has a cross feed index within ±.0001." The unique application of the PW-4 Post Decitron Counter controls this repeatability accuracy of the cross feed increment. Features . . . variable speeds . . . faster "slug set-up" . . . and easy to read dial setting.

The Reid Model 612 Slicer is driven by a DC motor and controlled by full wave rectified AC with DC ripples filtered in an LC circuit. AC power supply is regulated with the Voltage Regulator Transformer.

▶▶▶ FOR YOUR RELIABILITY-FACTOR GET ALL THE DETAILS ON THIS ALL-IMPORTANT NEW TOOL. FOR A DEMONSTRATION APPOINTMENT CALL W. P. FERGNANI IN BEVERLY, MASS.

WALKER 2-0811

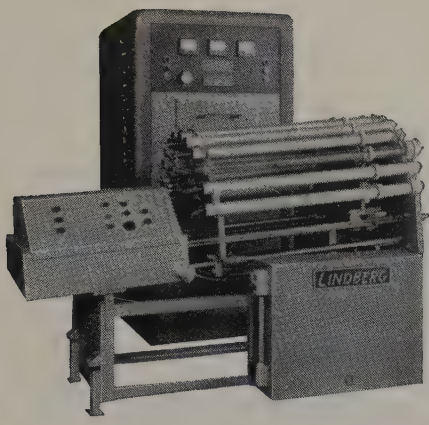
PRECISION SURFACE REID GRINDERS

Manufacturers of precision surface grinders for production and toolroom needs

REID PRECISION SURFACE GRINDERS

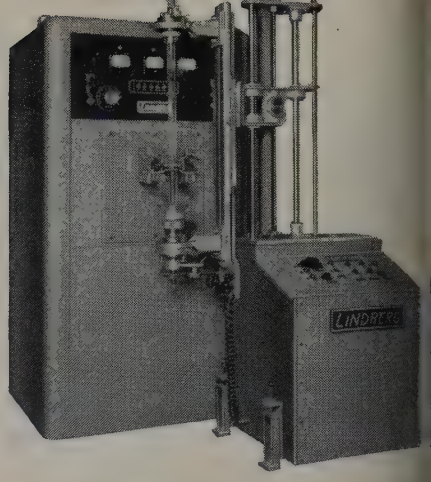
REID BROTHERS COMPANY, INC. / 135B ELLIOTT ST. / BEVERLY, MASSACHUSETTS

Circle No. 17 on Reader Service Card

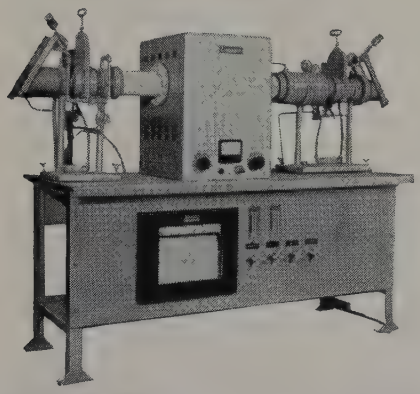


Horizontal Zone Scanner for zone purification of metallic germanium and other metallic and organic materials.

Low Temperature Furnace for solar cells and treatment of metals.



Vertical Floating Zone Scanner for accurat and precise production of hyper-pure semi conductor materials and metals.



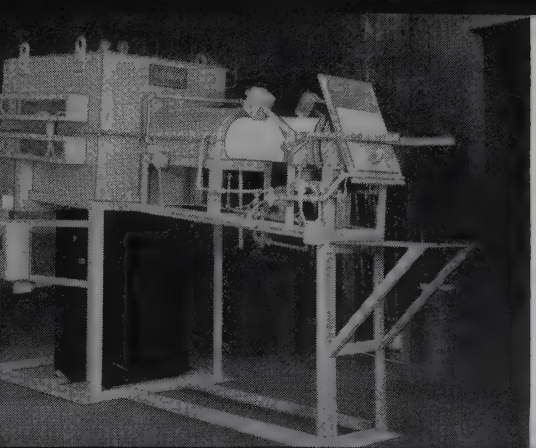
Batch Type Atmosphere Furnace for low temperature alloying.

We can engineer and produce refractory designs and mixes—dishes, boats, crucibles of zircon, zirconia, alumina, pure oxides, etc., for specific needs.

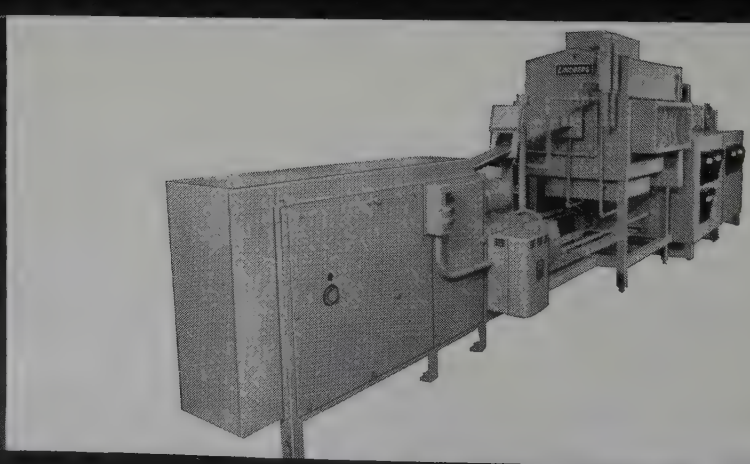
High Temperature Crucible Po Furnace for melting. Maximum temperature 1600°C.

for Semiconductors

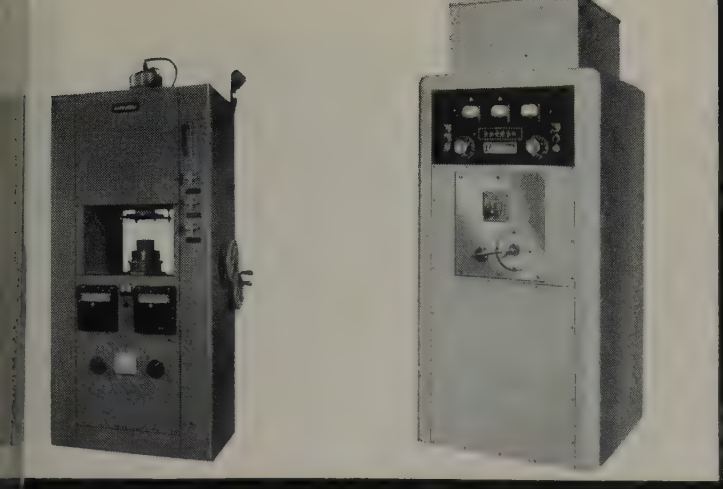
Lindberg no comprehensi



Hydrogen Atmosphere Furnace for reduction of germanium oxides and other materials.

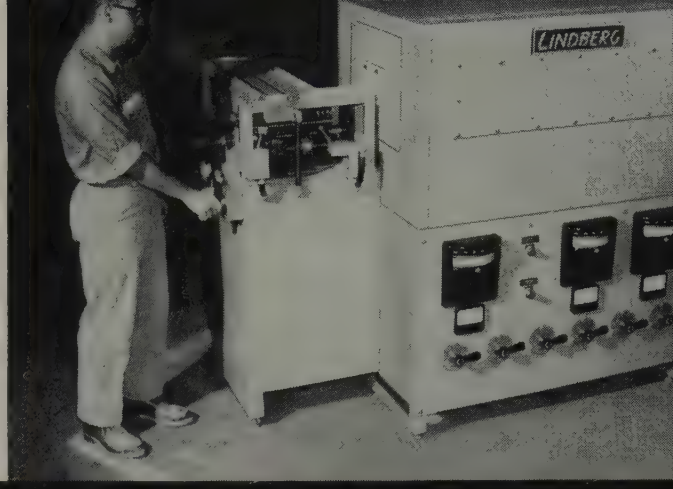


Hump Type Mesh Belt Conveyor Furnace for precision alloying of transistors and diodes.



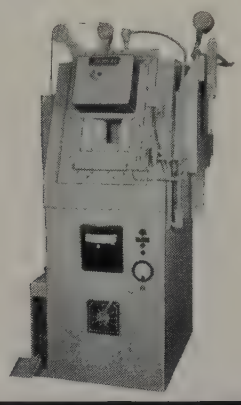
gh Temperature Tube Furce for germanium ingots.

Dual frequency unit for zone refining, one of a complete line of induction heating units.

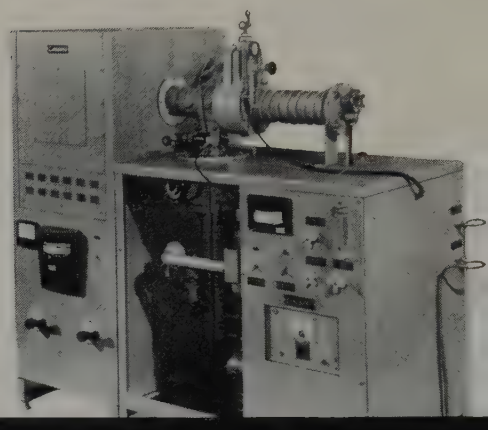


Mechanical Pusher Type Furnace for production of transistors by gas diffusion.

ecision Gas Diffusion Furnace with ultiple controls for quality transistor d semiconductor bodies.



High Temperature Gas-Tight Box Furnace for solar cells.



Vacuum unit for gas diffusion in alloy muffle or refractory.

ers the most advanced designs, the most e, in efficient, precise, production equipment.

Semiconductor and electronics manufacturers now can find in Lindberg one experienced source for dependable equipment for production of semiconductors, solid state and other electronic devices. The past several years a special staff of our experienced electronic, mechanical and electrical engineers, metallurgists, ceramicists and chemists has concentrated on the design and development of improved equipment for these uses. This group of experts, with many year's experience in all phases of the application of heat to industry, plus Lindberg's comprehensive research facilities provide the right combination to keep pace with the expanding requirements for reliable, efficient, precision equipment in these rapidly growing industries.

Shown here are some Lindberg units now in operation in plants throughout the country. We believe they provide collectively the most comprehensive line available today.

All of this equipment is operating in our research laboratories. We invite you to visit us, meet our able research staff, see at first hand—from crystal growing, to purifying materials, to finished product—how Lindberg offers a complete and outstandingly competent source for consultation on your semi-conductor or electronic production problems. For additional information please get in touch with your local Lindberg representative (See your classified phone book) or write directly to us.

Semiconductor Division

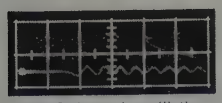
LINDBERG ENGINEERING COMPANY • **2489 West Hubbard Street, Chicago 12, Illinois**

Los Angeles plant: 11937 S. Regentview Avenue, Downey, California. In Canada: Birlefco-Lindberg Ltd., 15 Pelham Ave., Toronto 9, Ont.
Also, Lindberg plants in Argentina, Australia, England, France, Italy, Japan, South Africa, Spain, Switzerland and West Germany.

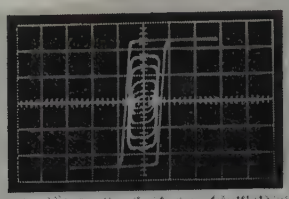
Circle No. 18 on Reader Service Card

You can do MORE with the NEW TEKTRONIX C-12 CAMERA than you can with any other Oscilloscope Camera

...picture this

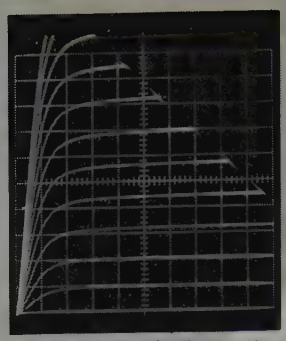


1 KMC damped oscillation (single shot at 2 nsec/cm).



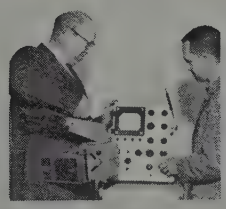
Typical hysteresis loops (multiple exposure of varying amplitudes).

Damped sine wave (multiple exposure using all 5 detent positions).

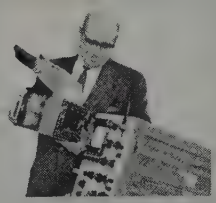


Family of characteristic curves (for NPN transistor).

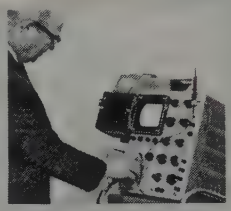
...like this



One-hand portability



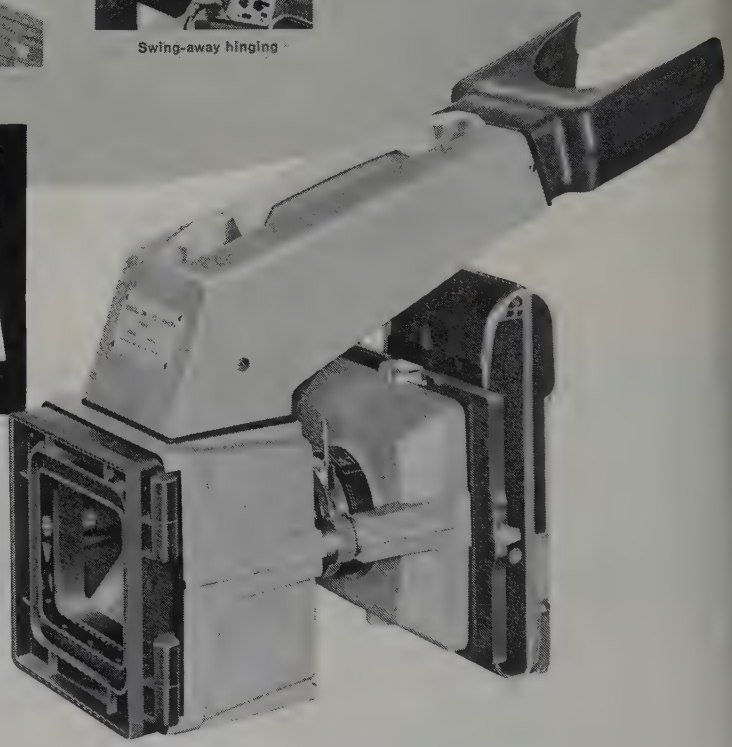
Lift-on mounting



Swing-away hinging

Comfortable viewing— with or without glasses

...only *with this* C-12 CAMERA



The C-12 Camera combines flexibility with simplicity. It offers you new convenience in undistorted viewing and direct recording of oscilloscope traces.

Here's why:

You can use Polaroid* or any conventional film.

You can use the unique sliding back, adjustable to horizontal or vertical. On this sliding back, you can interchange the parfocal, film-holding backs, lock them securely in 5 detent positions, also rotate them thru 90° increments (with the long axis of the film horizontal or vertical).

You can choose from 8 easily-interchangeable lenses — in varying object-to-image ratios and maximum aperture to f/1.5. The lenses are housed in uniform, pre-focused, calibrated mounts with keyed threads — so the shutter-speed and diaphragm-opening controls always appear at the same accessible position on the camera.

For more information about these and other features of the new C-12 Camera . . . and the many accessories designed for specialized applications . . . call your Tektronix Field Engineer.

C-12 CAMERA **$500**

Includes: f/1.9 Lens (with 1:0.9 object-to-image ratio) complete with cable release, Focusing Back, Polaroid Back, and Minute Timer.*

*Registered by Polaroid Corporation.

Tektronix, Inc.

P. O. Box 500 • Beaverton, Oregon
Phone MItchell 4-0161 • TWX—BEAV 311 • Cable: TEKTRONIX

TEKTRONIX FIELD OFFICES: Albuquerque, N. Mex. • Atlanta, Ga. • Baltimore (Towson, Md.) • Boston (Lexington, Mass.) • Buffalo, N.Y. • Chicago (Park Ridge, Ill.) • Cleveland, Ohio • Dallas, Texas • Dayton, Ohio Denver, Colo. • Detroit (Lathrup Village, Mich.) • Endicott (Endwell, N.Y.) • Greensboro, N.C. • Houston, Texas • Indianapolis, Ind. • Kansas City (Mission, Kan.) • Los Angeles Area (East Los Angeles, Calif., Encino, Calif. • West Los Angeles, Calif.) • Minneapolis, Minn. • New York City Area (Albertson, L.I., N.Y. • Stamford, Conn. • Union, N.J.) • Orlando, Fla. • Philadelphia, Pa. • Phoenix (Scottsdale, Ariz.) Poughkeepsie, N.Y. • San Diego, Calif. • San Francisco (Palo Alto, Calif.) • St. Petersburg, Fla. • Syracuse, N.Y. • Toronto (Willowdale, Ont.), Canada • Washington, D.C. (Annandale, Va.).

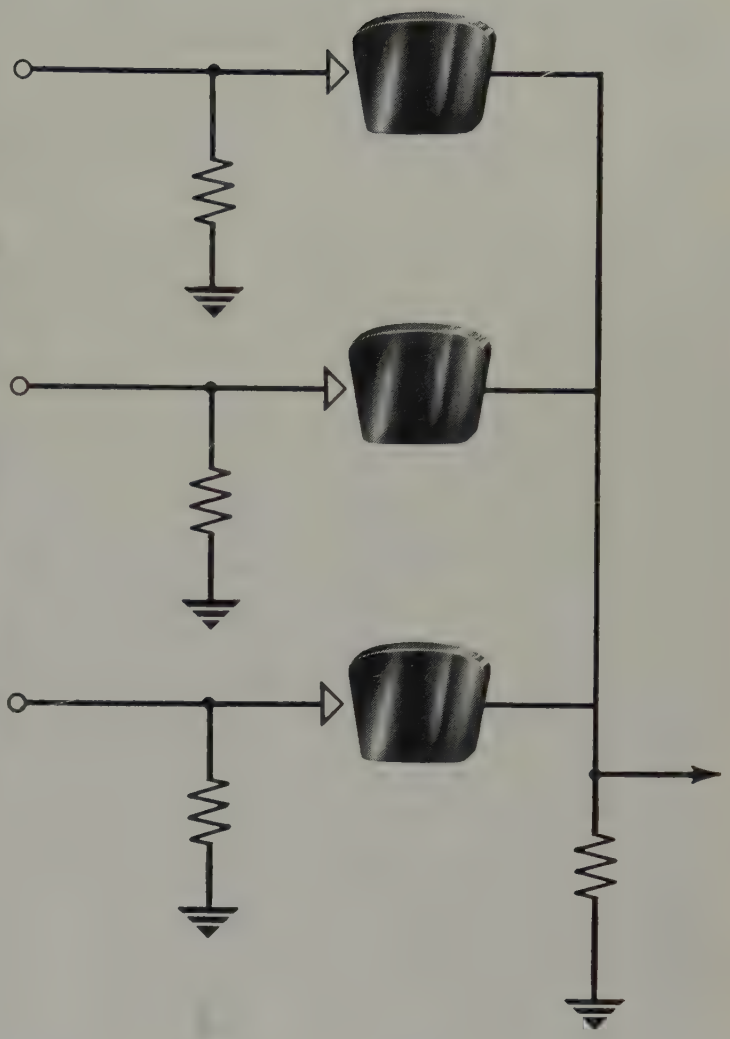
TEKTRONIX ENGINEERING REPRESENTATIVES: Hawthorne Electronics, Portland, Oregon • Seattle, Washington. Tektronix is represented in twenty overseas countries by qualified engineering organizations

In Europe please write Tektronix Inc., Victoria Ave., St. Sampsons, Guernsey C.I., for the address of the Tektronix Representative in your count

Circle No. 19 on Reader Service Card

LOGIC FOR DIODES:

GET ULTRA-FAST SWITCHING WITH SEMIMETALS' LOW-LIFETIME N-TYPE GERMANIUM



Semimetals produces gold-compensated germanium in extremely uniform N-type crystals. This proven material gives you highly reproducible results from batch to batch of diodes, no matter when you buy the monocrystals. Storage times are so brief that ultra-fast switching in the low nanoseconds is readily obtainable in your devices.

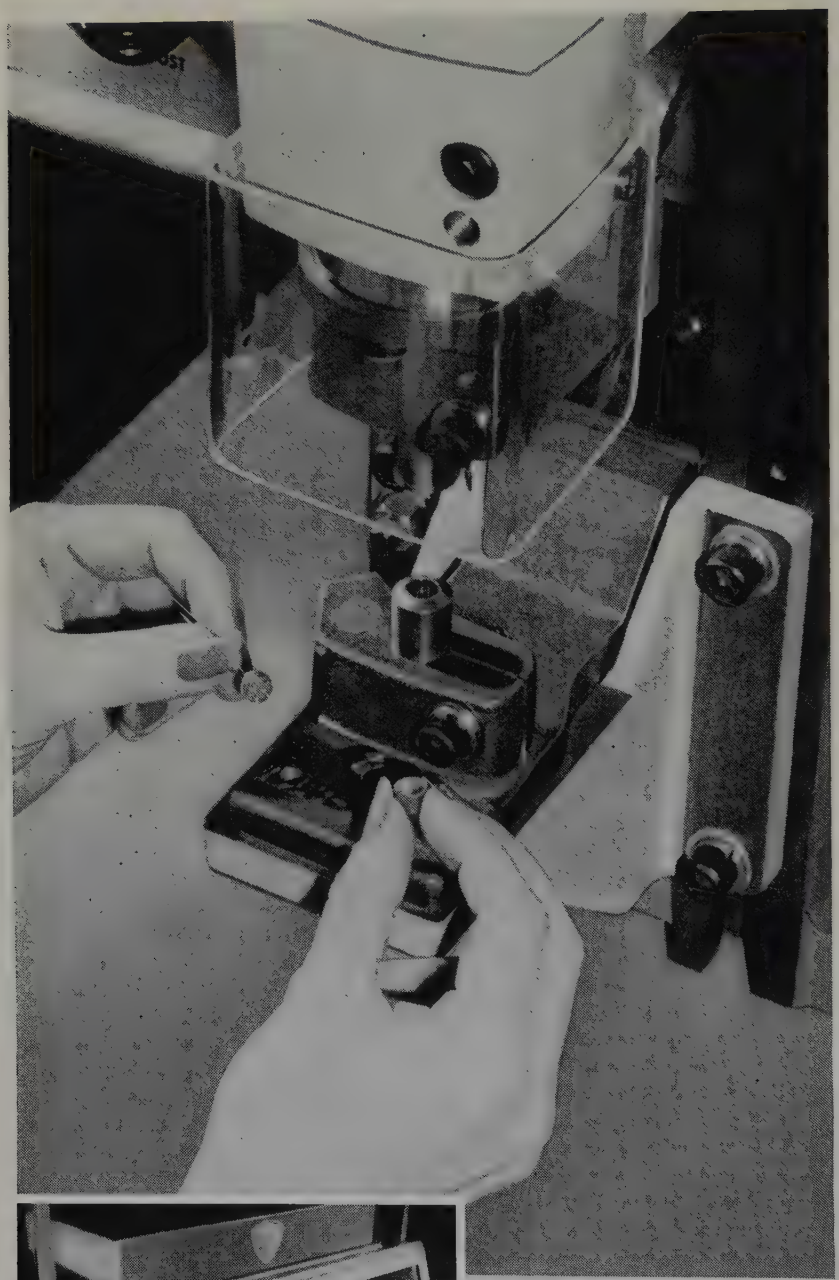
We believe, from experience, that our methods of gold-doping and crystal growing are the most reliable and uniformly effective known. Naturally, we also hold precise tolerances on other doping materials added to specification. If you are manufacturing or planning to manufacture ultra-high-speed diodes, see the prime source: Semimetals.

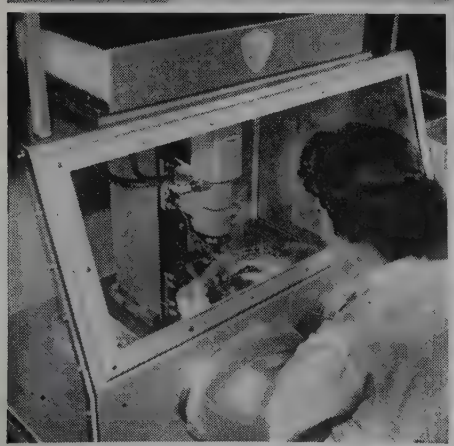
Also producers of high-quality monocrystal germanium and germanium or silicon infrared materials. Deliveries excellent on all materials.

SEMIMETALS, INC. 133-20 91st Avenue • Richmond Hill 18, New York • AXtel 7-0200

Circle No. 20 on Reader Service Card

FOR PRECISION WELDING OF TRANSISTORS AND COMPONENTS





RAYTHEON'S MODEL "M" WELDING HEAD

Newest development in precision welding of miniature parts.

The "M" head—Raytheon's completely new precision welding device—assures consistent welding performance even when joining miniature parts. The secret is the advanced design that achieves relatively low welding currents and electrode pressures.

The new head has extremely fast action and a new low-impact anti-hammer arrangement that extends electrode life many times. It has an air chamber that provides for a deflection of less than .003 inch under full pressure.

The "M" head—thoroughly tested in transistor production—can be mounted horizontally or vertically and is adaptable to dial feed or in-line feed for automated production.

THE UNIQUE ADVANTAGES of an "M" head installation will be obvious to you after reading the latest technical bulletins. Write for them today to Raytheon Company, Commercial Apparatus & Systems Division, Production Equipment Department, 1415 Boston-Providence Turnpike, Norwood, Massachusetts. In Canada, Raytheon Canada, Waterloo, Ontario.

FEATURES

- Can be used with any welder
- Horizontal or vertical operation
- Adaptable to dry box installations
- Quick, easy servicing, electrode changing
- Adjustable linear bushing and electrode alignment
- Long electrode life
- Minimum deflection

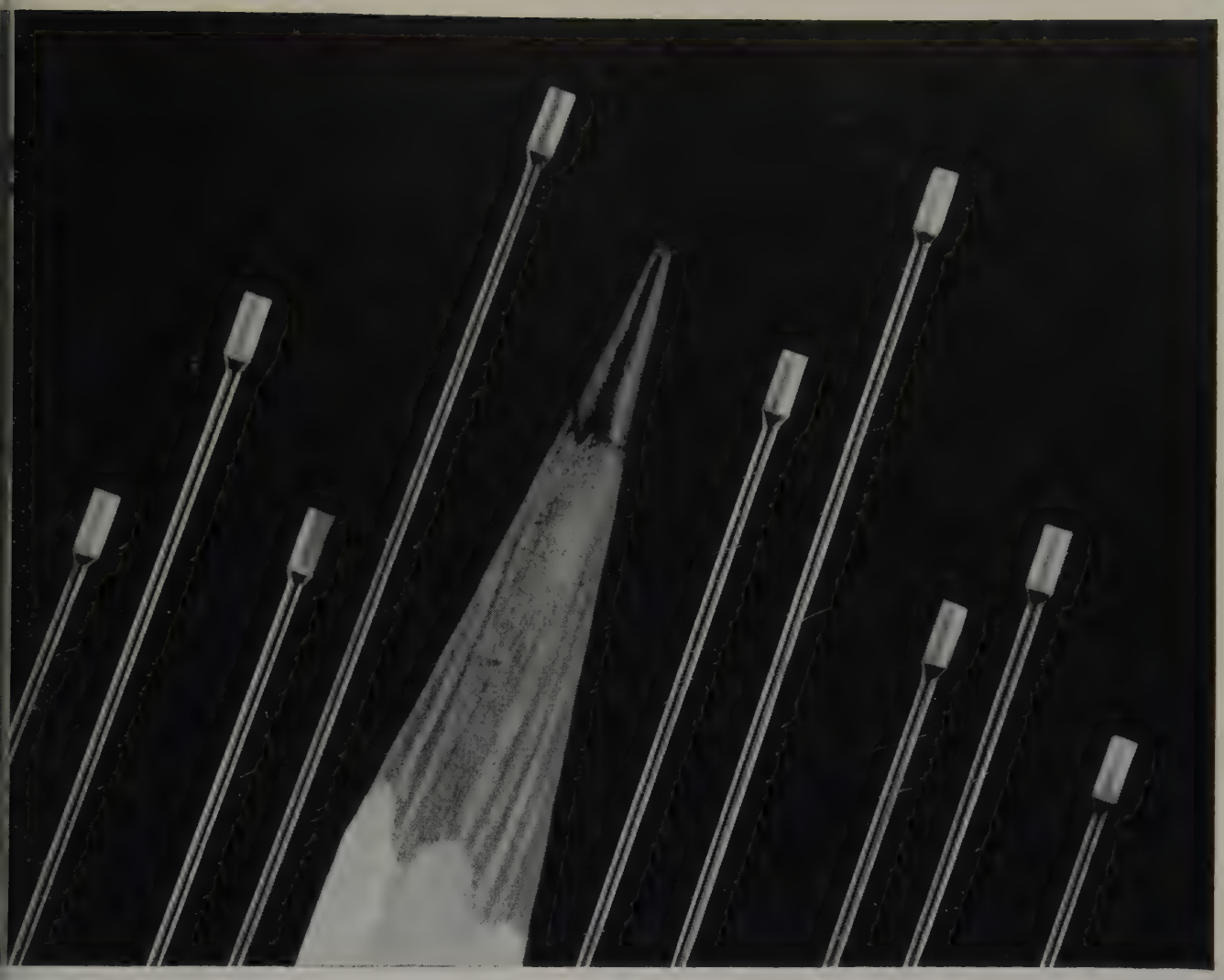
RAYTHEON

RAYTHEON COMPANY

COMMERCIAL APPARATUS & SYSTEMS DIVISION

A complete line of precision welding equipment for the electronics industry

Circle No. 21 on Reader Service Card



VEW SLANT ON DIODE LEADS

steps up reliability... cuts shrinkage

ow for the first time, Sylvania makes available mass oduction quantities of diode Dumet lead wires by uti- ing its fully automated production facilities. A typical ad wire features a slug made from specially developed ylvania diode Dumet .040″ in diameter x .100″ long. pigtail wire is concentrically welded to it and measures 20″ in diameter and up to 1½″ long.

esult? Semiconductor device manufacturers are assured f improved component reliability, significantly less rinkage, and small packages. You get better heat dis- pation from the semiconductor device, and may now te your devices at a higher wattage. (Naturally, the size of the slug and the wire can be tailored to your specifications within limits.)

This is just one more advance in welded assemblies from Sylvania. And whether you need hand-welded, semiauto- matic or fully automatic production techniques, Sylvania can do all to meet your requirements. At Sylvania, too, unique quality control is assured throughout.

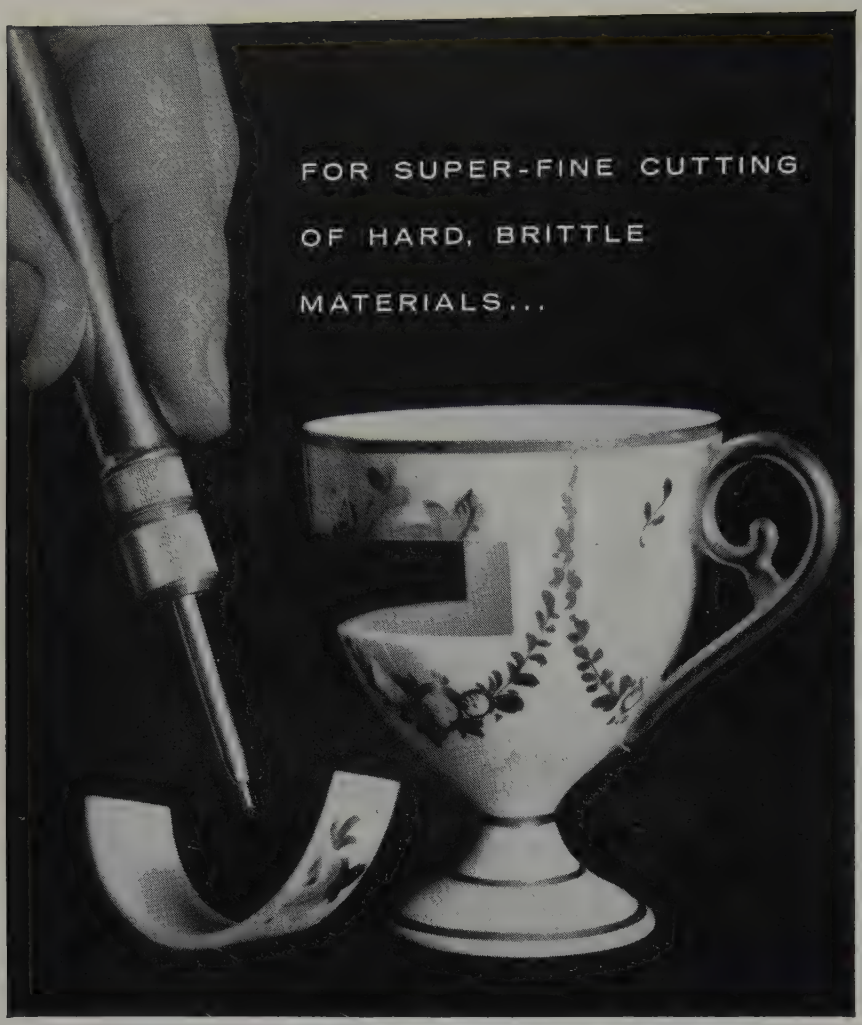
For full details on the new Sylvania diode lead—plus welds, cans, headers, connectors, and alloy cuts and leads, just write Sylvania Electric Products Inc., Parts Divi- sion, Warren, Pennsylvania.

SYLVANIA

Subsidiary of GENERAL TELEPHONE & ELECTRONICS

GENERAL SYSTEM

Circle No. 22 on Reader Service Card



THE S. S. White Industrial Airbrasive Unit

We don't recommend slicing up the family's fine Limoge China, but this does illustrate the precisely controlled cutting action of the S. S. White Airbrasive Unit. Note how clean the edge is, and how the delicate ceramic decoration is unharmed.

The secret of the Airbrasive is an accurate stream of non-toxic abrasive, gas-propelled through a small, easy-to-use nozzle. The result is a completely *cool* and *shockless* cutting or abrading of even the most fragile hard materials.

Airbrasive has amazing flexibility of operation in the lab or on an automated production line. Use the same tool to frost a large area *or* to make a cut as fine as .008"!...printed circuits...shaping and drilling of germanium and other crystals...deburring fine needles...cleaning off oxide coatings...wire-stripping potentiometers...engraving glass, minerals, ceramics. Jobs that were previously thought impossible are now being done.

Send us samples of your "impossible" jobs and we will test them for you at no cost.

SEND FOR BULLETIN 6006
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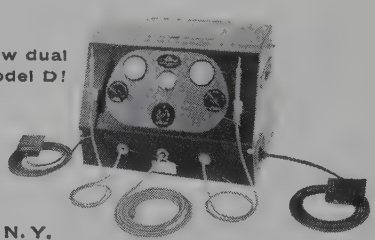

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Book Reviews

TITLE: Introduction to Electrical Engineering, Third Edition

AUTHOR: Robert P. Ward

PUBLISHER: Prentice-Hall, Englewood Cliffs, New Jersey

Introduction to Electrical Engineering is the third edition of a previously well-received book on basic electrical engineering. This edition has been updated and revised to include more examples and better network presentations.

The first chapters deal with an introduction to the topic and a description of electrical concepts, laws and units. It is interesting to note that all examples and concepts do not consider only the *a-c* or *d-c* circuits but rather deal with general expressions. The reader is immediately introduced to alternating current and some transient phenomena in addition to delta-wye networks and transmission lines. Chapter IV is an extensive treatment of network theory along the lines of the classical approaches.

A substantial portion of the book is devoted to magnetic circuit concepts. Chapter VII develops many of the basic theories. Here again, the treatment is very general covering both field theory and magnetic circuits (Chapter IX). Electromagnetic induction and motional electromagnetic force are discussed in Chapter XI.

The balance of the book covers electric field theory conduction in liquids and gases, semiconduction and transient response of simple circuits—some very advanced topics for an introductory textbook.

Introduction To Electrical Engineering is certainly an excellent text. The approach to the material is succinct and interesting. A large number of illustrative examples and fine line drawings do much to clarify the text. This book is well recommended as a basic text.

TITLE: Progress in Vacuum Science and Technology

AUTHOR: Edited by A. S. D. Barrett

PUBLISHER: Pergamon Press, New York

Progress in Vacuum Science and Technology is a collection of papers on vacuum practice, techniques and science.

Vacuum science is devoted mainly to the study of the techniques, problems and allied fields of vacuum technology with an emphasis here on work applicable to the manufacture of tubes.

There are papers discussing problems in the tube industry, getting processes, vacuum metallurgy, fumigation and drying. A good part of the book is devoted to a rather interesting paper by Watt on molecular or high vacuum distillation. There is also a paper on education in vacuum practice at British colleges, a somewhat out-of-context but enlightening description.

Progress in Vacuum Science and Technology is an interesting and informative collection of papers by several experts in the field. The book will be of special interest to the tube designer and physicist and is well written and illustrated.

By Stephen E. Lipsky

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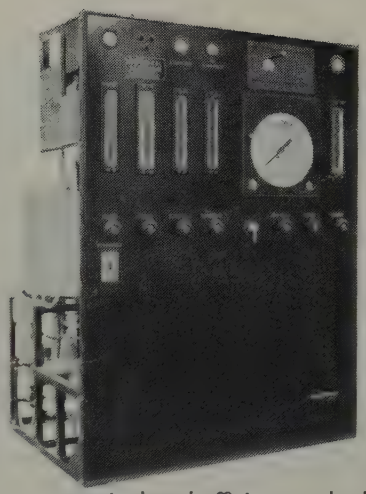

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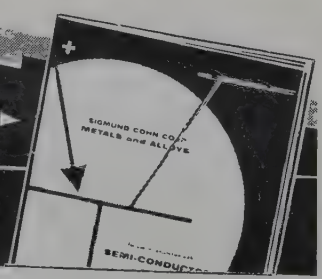

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Personnel

Standard Rectifier Corporation announced the appointment of Jack Gillette as Associate Director of Engineering. He was formerly Chief Electronics Engineer for Hughes Semiconductor and will be responsible for the product, development, process and application engineering for SRC's semiconductor product line.

PRL Electronics, Inc., Rahway, New Jersey, announces the appointment of Stephen Krsna to the position of chief engineer. Previously, he was on the engineering staff of the NJE Corporation. PRL produces specialized test equipment and power supplies.

William H. Berno and Leonard E. Gilmore have been appointed Field Sales Engineers for Texas Instruments Incorporated Geosciences & Instrumentation division's Instrumentation group, O. F. Henning, Marketing Manager, has announced. Mr. Berno has been assigned to TI's Detroit office to provide additional customer service in Michigan and northern Ohio. Mr. Gilmore will service New England from the company's Garden City, L. I., New York office.

Dr. J. Sterling Livingston, Professor of Business Administration of Harvard University, has recently joined the top management of TYCO Incorporated, a business organization recently formed to sponsor and combine advanced technical industries, as a director of the corporation. Dr. Livingston will continue at Harvard and as president of Harbridge House, Inc., a management development and consulting firm he founded in 1949.

Hollywood Radio & Electronics, Inc. has announced the election of Donald Aarons as Vice-President and Member of the Board. Mr. Aaron's responsibilities will encompass that of Director of Sales. G. J. Rothman, Chairman of the Board, also announced that Clint Labin has been appointed Manager of Internal Sales Administration.

H. J. Elias has been named manager of signal diode manufacturing in General Electric's newly-formed Signal Diode Project in its Semiconductor Products Department. Mr. Elias was previously manager of quality control for the Department's Syracuse Plant.

W. C. "Red" Schultz has been transferred and promoted to the position of national distributor sales manager for the Semiconductor Division of Hoffman Electronics Corporation, headquartered in El Monte, California.

Robert C. Sprague, chairman of the board and chief executive officer of Sprague Electric Company, has announced the following promotions: William J. Nolan, senior v.p. in charge of legal affairs; Neal W. Welch, senior v.p., marketing and sales; Wilbur A. Lazier, senior v.p., technical director; Robert C. Sprague, Jr., senior v.p., industrial relations; David B. Peck, v.p., special products; Hollis R. Wagstaff, v.p., fiscal; Carroll G. Killen, v.p., industrial and military sales; Bruce R. Carlson, v.p., corporate planning and systems.

Notes . . .

The appointment of Frank H. Bower to the newly-created post of manager of research and development contracts for the Semiconductor Division of Sylvania, has been announced by Dr. J. Earl Thomas, director of research and engineering for the division.

Bernard Reich has been named president of Molecular Electronics, Inc., designer and manufacturer of test equipment for measurement and characterization of semiconductor devices. Molecular Electronics, Inc. is a wholly-owned subsidiary of Precision Circuits, Inc.

Hughes Aircraft Company's semiconductor division has reorganized its operations and the following new managers have been appointed reporting to Operations manager William R. O'Hara: John A. Locke, germanium diodes; John C. Clorey, silicon diodes; C. J. Roach, transistors; George C. Messenger, special products; Jon H. Myer, materials; Robert E. Carr, rectifiers. The parallel marketing sales managers are Herbert F. Wander, transistors and special assemblies, and John Crimp, Diodes.

Robert J. Cooley has been appointed Technical Director of Penfield Manufacturing Co., Inc., Meriden, Conn., designer and manufacturer of industrial demineralizers.

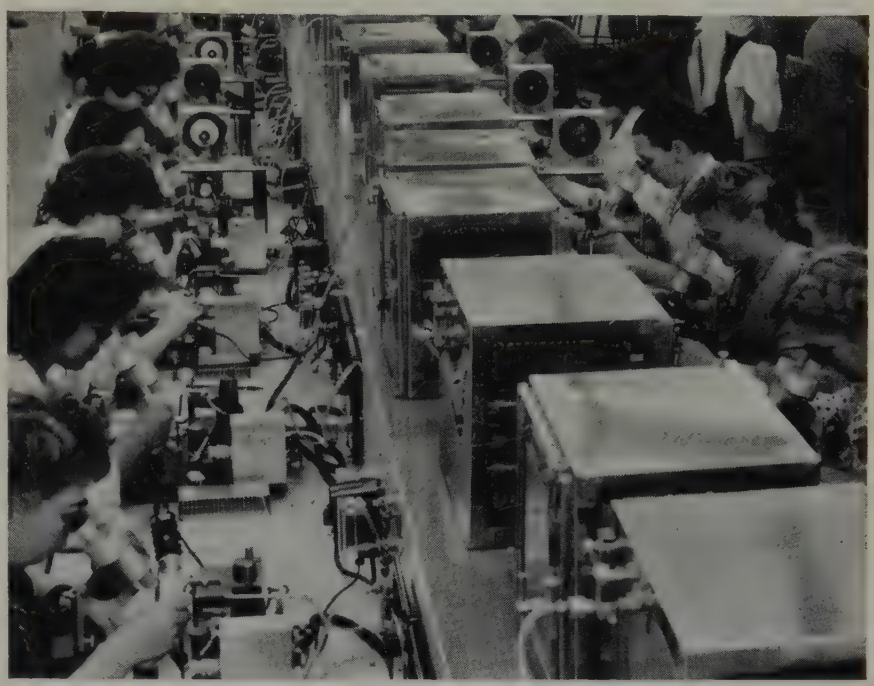
Joseph King, Diode and Rectifier Product Manager for Sperry Semiconductor Division of Sperry Rand Corporation, announced the appointment of Peter H. Dirnbach as Chief Engineer—Diodes and Rectifiers. He will be responsible for directing all engineering activities on this line.

Leonard Murchison has been named to the new post of national accounts manager, semiconductors, for the CBS Electronics Division of Columbia Broadcasting System, Inc., in an announcement by R. Yeiter, semiconductor sales manager. Mr. Murchison was West Coast regional sales manager, semiconductors.

Michigan State University has announced the appointment of Dr. Lawrence J. Giacoletto as a professor in the Department of Electrical Engineering and the Division of Engineering Research within the College of Engineering, according to L. W. Von Tersch, Head, Department of Electrical Engineering. Dr. Giacoletto was for four years the Manager of the Electronics Department of the Ford Motor Company Scientific Laboratory.

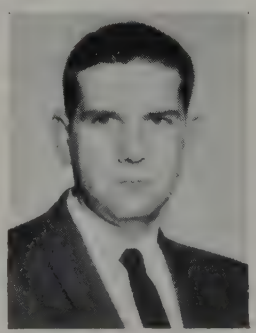
Latest Field Engineering personnel changes at Tektronix: Doug Curé, formerly of the Albuquerque Field Office, and Dean Butts, formerly of the East Los Angeles Field Office, have exchanged territories. Tom Long, formerly of the Chicago Field Office, will now be available at the Dayton Field Office, while Ralph Ebert has become manager of the Chicago Field Office. Also at Chicago as a new Field Maintenance Engineer is Larry Hudetz from Portland.

AO Stereo Microscopes lick unusual assembly problems at Fairchild Semiconductor



A typical assembly line at Fairchild Semiconductor Corporation's silicon transistor plant in Mountain View, California.

Fairchild Semiconductor Corporation, one of the nation's largest manufacturers of semiconductor products and electronic components, needed microscopes, hundreds of them, for the assembly of their extremely small component parts. But they had specific problems to overcome, such as extreme temperature changes, rough handling and operator fatigue. Let their transistor Plant Manager, Mr. Charles Sporck, tell you, in his own words, how these problems were solved.



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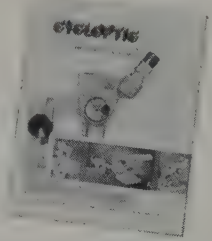

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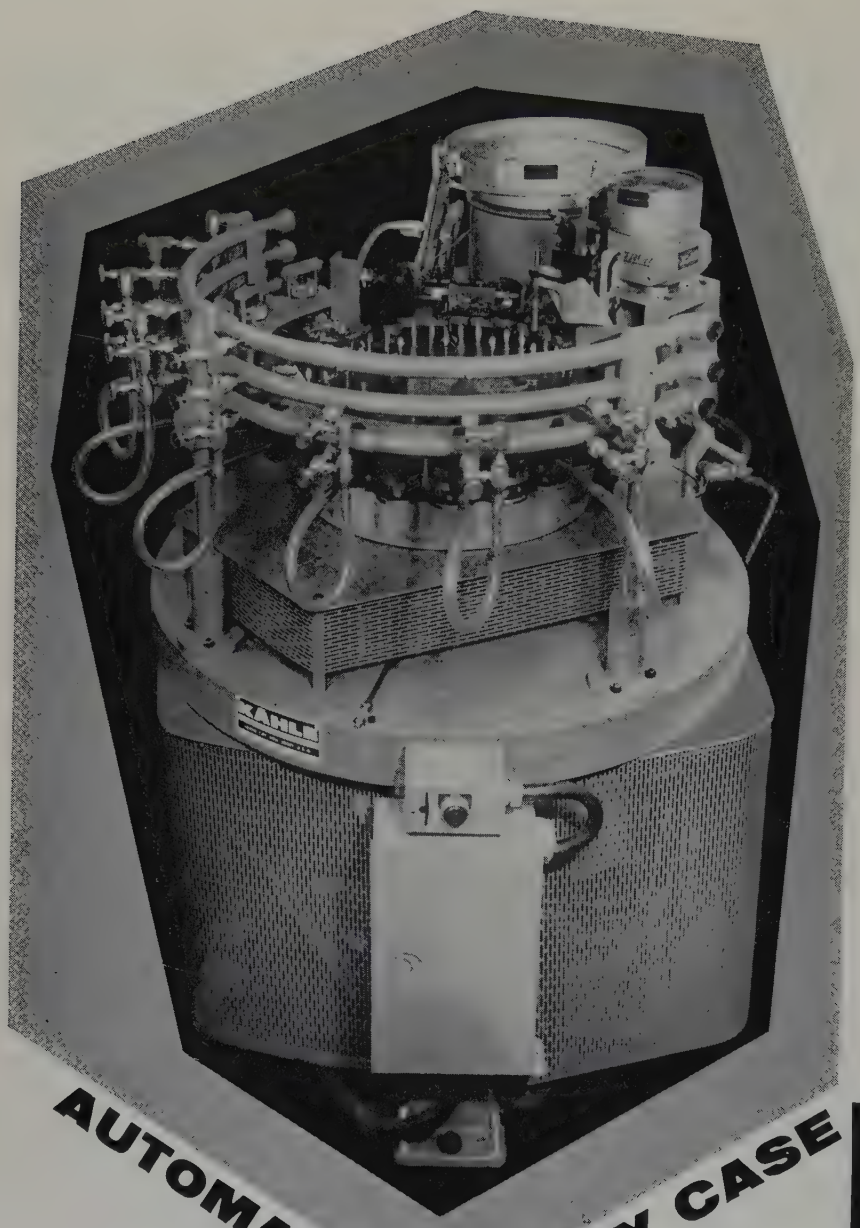

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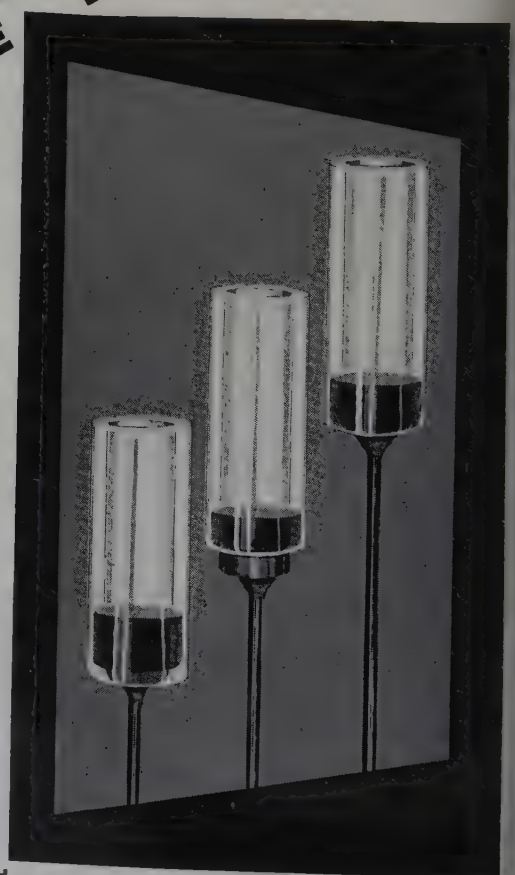

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Editorial . . .

The P-N Junction Diodes

The *p-n* junction diode, once considered a device of rather secondary importance with respect to the transistor, has been gaining in respect steadily in recent years. At first it was considered to be only a nonlinear resistance and efforts were made to reduce its reactive properties with the use of appropriate geometries and short leads. The device was used primarily as a switch or as a mixer. Later it was noted that the nonlinear properties of its intrinsic capacitance could be put to good use since the device could be made to operate as a variable capacitor with sufficiently large Q factor. Efforts were developed to improve the Q and to increase the capacitance variation per unit voltage. More recently, several investigations have been initiated to try to enhance the inductive properties of the diode in the forward bias direction, utilizing the retarding properties associated with the phenomenon of diffusion. In the meantime it has been discoverd that by appropriate doping the diode may be made to act as a negative resistance (tunnel diode) providing thereby opportunities for operation as oscillator or as amplifier.

The research for the development of a semiconductor diode inductance is prompted by the desire of replacing bulky inductors represented by conventional air- or magnetic-core coils. However, in order that such an inductor may be useful, it must possess a reasonable value of Q. In a recent article (*Trans. IRE-ED*, October 1960) Ladany has proposed a new diode geometry which seems to have some possibilities for the purpose of designing an inductor. This is a planar, narrow-base, abrupt junction *PIN* diode; the emitter is a highly doped *p* region, the base is intrinsic and the terminals constitute infinite recombination velocity contacts. When a difference of potential V is applied across the diode, this is partitioned between the junction and the base. As this voltage is increased, the carrier injection, which is controlled by the junction, increases, and the conductivity of the base rises correspondingly.

The interesting characteristic of the diode is that the drift current which occurs in the base is controlled in magnitude by the voltage across the barrier. Assume that a step voltage is applied across the diode; a current is injected into the base, but this takes a time of the order of $d^2/2D$ to diffuse through the base. In the latter expression d is the base thickness and D is the diffusion coefficient. Correspondingly, the current increases from a negligible value to the value V_2/R_f, where V_2 is the voltage across the base and R_f is the base resistance. Letting

$$\frac{di}{dt} = V_2/R_f\Delta t$$

where $\Delta t \cong d^2/2D$, it follows that the equivalent inductance is

$$L = V_2/\frac{di}{dt} = R_f\, d^2/2D.$$

The resistance R_f is proportional to $d/\sigma A$ (where A is the diode cross-section) and is a function of V_2. More rigorous expressions for the inductance may be obtained solving the continuity equations for the carriers in the base. It is found that the inductive reactance is maximum near the zero bias and decreases thereafter. Its Q factor, however, always remains smaller than unity.

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Bell Laboratories scientists chose a ruby amplifier because it's uniquely free of "noises" that interfere with radio signals. For example, it doesn't have the hot cathodes or hurtling electrons that generate noise in conventional amplifiers. It is so quiet that only the noise made by matter itself in heat vibrations remains. But at a temperature close to absolute zero, this also is silenced. Even very faint signals from satellites can be clearly amplified and studied for their possibilities.

Bell Laboratories scientists were first to discover that matter itself generates electrical noise. They also discovered that stars send radio waves, and thus helped found radio astronomy. It is particularly fitting that the same scientists, in their endless research on noise, should now battle this number-one enemy of telephony in the dramatic new field of communication via satellites. The ultimate goal, as always, is the improvement of your Bell System communications services.

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WORLD CENTER OF COMMUNICATIONS RESEARCH AND DEVELOPMENT

The Design of High Stability D.C. Amplifiers

PAUL J. BENETEAU*

Several circuits are available for d-c amplifiers. For a high degree of temperature stability, chopper methods are usually superior to the conventional difference amplifier proposed by Slaughter. However, recent advances in transistor technology make it worthwhile to reconsider the Slaughter circuit. A new circuit is shown that has, with unselected transistors, a drift referred to the input of the order of 10 μV/°C, or at least as good as was previously available by using highly selected units in the conventional circuit.

THERE ARE MANY REQUIREMENTS for direct-coupled amplifiers, including for example, sensor (e.g. strain gauge) amplifiers, meter amplifiers to increase meter sensitivity, high-impedance transistor voltmeters and operational amplifiers. It has been very difficult to design stable *d-c* amplifiers using transistors, due to the serious variation of transistor parameters with temperature, particularly the base-emitter voltage (V_{BE}), collector-base leakage current (I_{CBO}), and h_{FE}. Since these amplifiers cannot be *a-c* coupled, it is obvious that a shift in operating point cannot be distinguished from a drift in input voltage, and the problem thus reduces to making both the operating point and the gain constant with temperature.

Several circuits have been proposed to reduce this drift. Mechanical choppers have been widely used to convert the *d-c* voltage into an *a-c* voltage; the resulting voltage is amplified and rectified (ref. 1). This method suffers from the inherent very low frequency limitation of the mechanical chopper, and the sometimes questionable reliability of a mechanical component. A second scheme proposed by Goldberg (ref. 2) uses a chopper-stabilized arrangement, which again has the disadvantage of a mechanical component. These difficulties can be removed by using transistor choppers, but there are other considerations that still make straight *d-c* amplifiers preferable. Slaughter (ref. 3) has used to a very good advantage a differential amplifier that reduces the drift to the *difference* in the parameters of the two transistors. By careful selection of transistors, it has been possible to obtain equivalent drifts referred to the input of the order of 20 μV/°C. The limiting factor, however, remains the differences in V_{BE} and h_{FE}, and only by reducing these can more stability be obtained in this circuit. For this reason, the Slaughter circuit has been somewhat inferior to the chopper-stabilized methods.

Recent significant advances in semiconductor technology by which junction surfaces are passivated (e.g. Fairchild 2N1613) have resulted in V_{BE} tracking between unselected transistors superior by an order of magnitude over previously available devices. This technique also results in very much lower I_{CBO}'s and very low noise figures. It is therefore worth reconsidering the Slaughter circuit using these surface-treated unselected units to determine the drift that can be obtained. Further, a different circuit is proposed that largely eliminates the drift due to the variations in h_{FE}. In this circuit, the drift becomes dependent primarily on the difference of V_{BE}'s between the two transistors, and since this difference is much less with the surface-treated transistors than with conventional transistors, a much lower drift can be expected.

It will be shown subsequently that this circuit results in drifts of the order of 10 μV/°C; these drifts were previously unattainable with unselected units, and are at least as good as were previously attainable with highly selected units. Improvements of 3.4:1 and 5:1 over the Slaughter circuit were realized using the same transistors in each circuit.

Conventional Differential Amplifier

A conventional direct-coupled differential amplifier is shown in *Fig. 1*. This circuit was first analyzed by Slaughter (ref. 3).

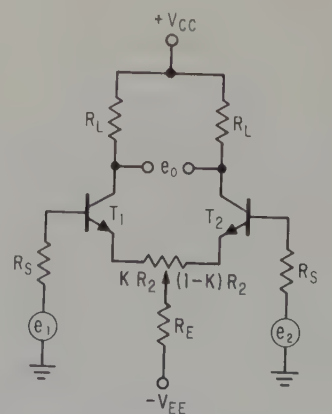

Fig. 1—Conventional direct coupled differential amplifier.

*Fairchild Semiconductor Corp., Mountain View, Calif.

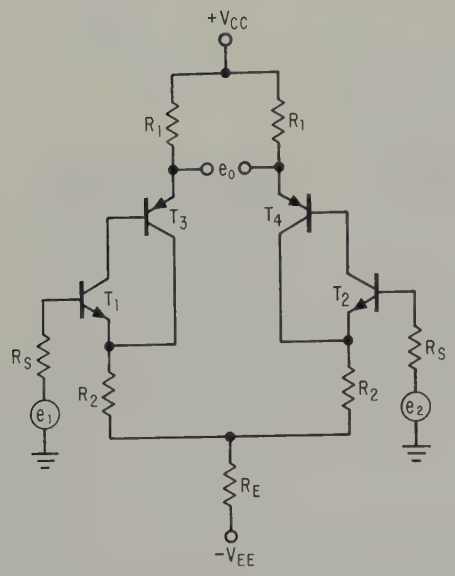

Fig. 2—New circuit using complementary pairs.

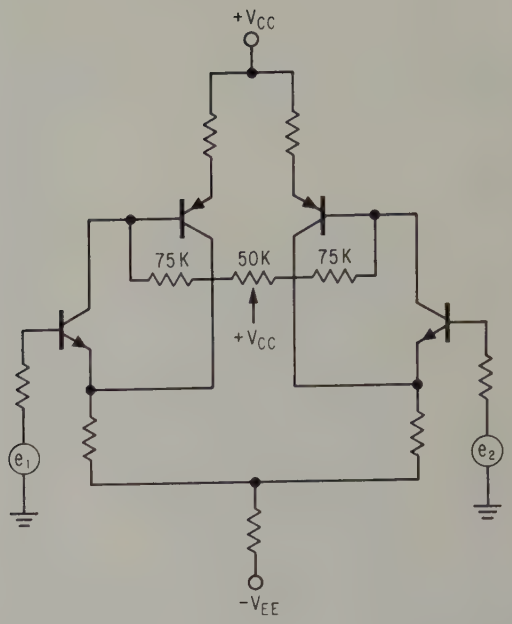

Fig. 3—Circuit similar to that of Fig. 2 but with provisions for zero-adjust.

It can be shown with some effort that

$$e_0 \simeq A\Big[(V_{BE_2} - V_{BE_1})\,(2\,h_{FE_1}\,h_{FE_2}) + (e_1 - e_2)$$
$$(2\,h_{FE_1}\,h_{FE_2}) + R_S(I_{CBO_1} - I_{CBO_2})\,(2\,h_{FE_1}\,h_{FE_2})$$
$$+ (e_1 - V_{BE_1} + V_{EE})\,\frac{(R_S + h_{FE}\,R_2)}{R_E}\,(h_{FE_2} - h_{FE_1})\Big] \quad (1)$$

where

$$A = \frac{-R_L}{(R_S + h_{FE}R_2)\,(h_{FE_1} + h_{FE_2})}$$

$$h_{FE} = Kh_{FE_1} = (1 - K)h_{FE_2}$$

and

$$h_{FE_1} = I_{C_1}/I_{B_1},\ h_{FE_2} = I_{C_2}/I_{B_2}.$$

The approximations used are

$$1 + h_{FE_1} \simeq h_{FE_1},\ 1 + h_{FE_2} \simeq h_{FE_2},$$
$$R_E \gg K\,R_2,$$

and that

$$h_{FE}R_E \gg R_S;$$

These are good assumptions for surface-passivated silicon devices used in a practical amplifier.

It is thus apparent that for $(e_1 - e_2) = 0$, the output will be zero only for $(V_{BE2} - V_{BE1}) = 0$ and $(h_{FE2} - h_{FE1}) = 0$ where the I_{CBO}'s are small, although for R_E very large, e.g. a common-base transistor constant current source where R_E might be of the order of megohms, the fourth term will tend to a very small value. Unfortunately the gain term is highly temperature sensitive, and even if two transistors are closely matched for V_{BE} and a large R_E is used, the output will still be a function of temperature for fixed input. This is a serious source of drift in this amplifier.

A More Stable Differential Amplifier

A new circuit* is shown in *Fig. 2*. It consists of two complementary pairs, with the collector current of the *npn* transistors feeding directly into the bases of the *pnp*'s. Thus, the base current of the *npn* transistors will be very small, and the temperature variation of h_{FE} will produce a small change in voltage across R_S, the source resistance, since the base current is already small to start. Middlebrook and Mead (ref. 4) have used one such pair to good advantage in obtaining a high input impedance amplifier.

An analysis of this circuit is carried out in the Appendix. It is shown that

$$e_0 \simeq \frac{-R_1}{R_2}\,[(e_1 - e_2) - (V_{BE_1} - V_{BE_2}) - R_S\,(I_{CBO_1} - I_{CBO_2})] \quad (2)$$

the only assumptions made being well within 1% for a practical amplifier. It is seen that the output voltage is independent of the h_{FE}'s of the transistors, thus eliminating a serious cause of drift of the Slaughter circuit. Further, I_{CBO} is extremely low for surface-passivated units. At 100°C, the typical I_{CBO} is 0.05 μa. Assuming an R_S of 1 K, this would yield a drift of the order of tens of microvolts for the I_{CBO} term, as compared to hundreds of microvolts for the $(V_{BE1} - V_{BE2})$ term. Thus, the I_{CBO} term is frequently negligible, although at very high temperatures it may predominate, particularly for source resistances greater than 10 K.

Since the drift depends primarily on the V_{BE} differ-

*A modification of a circuit described by Middlebrook and Mead (ref. 4); this modification was suggested by D. H. Hilbiber of the Fairchild Semiconductor Corporation. (ref. 5).

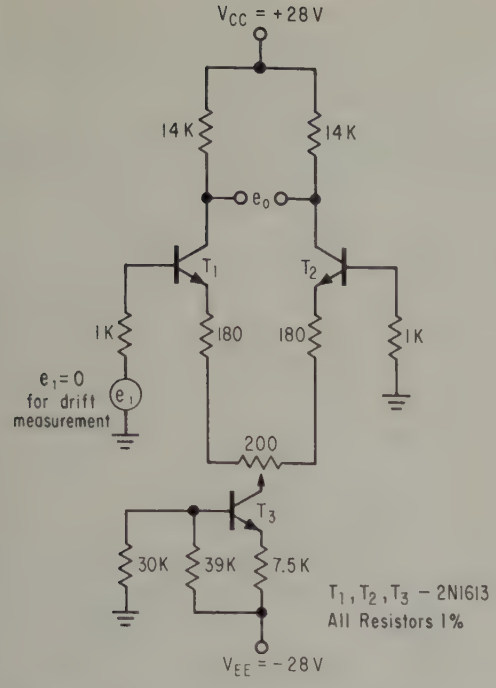

Fig. 4—Slaughter circuit used in obtaining experimental results.

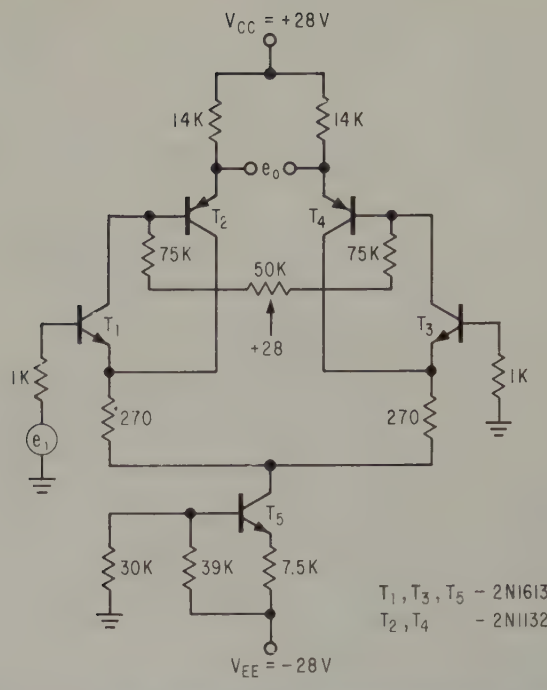

Fig. 5—New circuit used in obtaining experimental results.

ence, and since this difference has been improved by an order of magnitude over existing devices, it follows therefore that this circuit, using unselected surface-treated units, can result in drift figures previously unattainable. These results are verified in what follows.

If the V_{BE}'s are different but track well, a zero adjustment can be made as in *Fig. 3*†. It is to be noted that the characteristics of the *pnp* transistors are unimportant, and that matching is unnecessary.

Experimental Results

Both the Slaughter circuit and the new circuit were tried using two pairs of 2N1613's chosen at random. The transistors were inserted in a bath of silicon oil which was heated to 150°C and continually stirred. Although this precaution may seem extreme, it is to be noted that a difference of only 0.01°C in the junction temperature of the *npn* transistors will result in an equivalent drift referred to the input of 0.01 x 2.2 millivolts or 22 microvolts. Since it was hoped to get drifts of this order or less, it is obvious that a conventional heat sink is probably inadequate. Certain improvements in technology presently being investigated may reduce the seriousness of this problem.

The circuits used are shown in *Figs. 4* and *5*. The results are shown in Table I.

The performance of these transistors in the Slaughter circuit is somewhat superior to that generally obtained using other transistors; the improvement is not marked, however, due to the ΔV_{BE} being the only variable which has been improved. The drift due to variations in h_{FE} remains.

†Suggested by F. Carlson of Fairchild Controls Corporation.

The performance of the new circuit is, however, clearly superior. An improvement of 3.4:1 was observed for Pair 1 and 5:1 observed for Pair 2.

Conclusions

Unselected surface-passivated units used in the new *d-c* amplifier circuit give performance better than the best previously attainable using conventional highly selected transistors in the Slaughter circuit. It is expected that this circuit will have many advantages over chopper circuits, namely higher speed, lower noise, less complexity and more reliability.

Acknowledgements

The author would like to thank D. H. Hilbiber for suggesting the advantages of this circuit and H. Suzuki and L. Blaser for their careful measurements.

Appendix I—Table of Important Symbols

$$A = \frac{-R_L}{(R_S + h_{FE}\,R_2)\,(h_{FE_1} + h_{FE_2})} \quad \text{(see } \textit{Fig. 1}\text{)}$$

$h_{FE_1} = I_{C1}/I_{B1}$, $h_{FE_2} = I_{C2}/I_{B2}$.

Table I — Drift Comparison

Circuit	Equivalent Drift Referred To Input (μV/°C) 25°C - 150°C	
	Pair 1	Pair 2
A (Slaughter Circuit)	24	60.5
B (New Circuit)	7.1	12

$h_{FE} = K\,h_{FE_1} = (1 - K)\,h_{FE_2}$ (see *Fig. 1*)

I_{CBO_1} etc. = I_{CBO} of transistor T_1, etc.

R_S = Source Resistance (see *Fig. 1* and *2*)

V_{E_1}, V_{B_1} = voltage of emitter of T_1, voltage of base of T_1, etc.

V' = voltage common to both pairs. (see *Fig. 6*)

Appendix II—Analysis of the Two Feedback Pairs

The simplest way to analyze this amplifier is to first consider one pair only. See *Fig. 6*.

If I_{B1} is the base current of T_1, $h_{FE1}I_{B1}$ flows into the collector of T_1 from the base of T_3. Therefore, the collector current of $T_3 = h_{FE3}h_{FE1}I_{B1}$.

Then I_2, the current flowing through R_2, is made up of the emitter current of T_1 plus the collector current of T_3. Therefore,

$$I_2 = (1 + h_{FE_1})\,I_{B_1} + h_{FE_1}h_{FE_3}I_{B_1} \simeq I_{B_1}\,h_{FE_1}\,(1 + h_{FE_3}), \qquad (3)$$

usually to within 0.1%.

Let V_{B1} be the base voltage of T_1 and V_{E1} the emitter voltage of T_1. Now,

$$I_{B_1} = \frac{1}{R_S}\,[e_1 - I_{CBO_1}\,R_S - V_{B_1}]$$

$$= \frac{1}{R_S}\,[e_1 - I_{CBO_1}\,R_S - (V_{BE_1} + V_{E_1})]$$

$$= \frac{1}{R_S}\,[e_1 - I_{CBO_1}\,R_S - (V_{BE_1} + I_2\,R_2 + V')]$$

$$= \frac{1}{R_S}\,[e_1 - I_{CBO_1}\,R_S - V_{BE_1} - I_{B_1}\,h_{FE_1}\,(1 + h_{FE_3})\,R_2 - V'] \qquad (4)$$

Solving (4) for I_{B1} yields

$$I_{B_1} = \frac{e_1 - I_{CBO_1}\,R_S - V_{BE_1} - V'}{R_S + R_2\,h_{FE_1}\,(1 + h_{FE_3})} \qquad (5)$$

Letting e_{03} be the output voltage on the emitter of T_3,

$$e_{0_3} = V_{CC} - I_{E_3}\,R_1$$

$$= V_{CC} - h_{FE_1}\,(h_{FE_3} + 1)\,I_{B_1}\,R_1$$

$$= V_{CC} - h_{FE_1}\,(1 + h_{FE_3})\,R_1 \left[\frac{e_1 - I_{CBO_1}\,R_S - V_{BE_1} - V'}{R_S + R_2\,h_{FE_1}\,(1 + h_{FE_3})}\right].$$

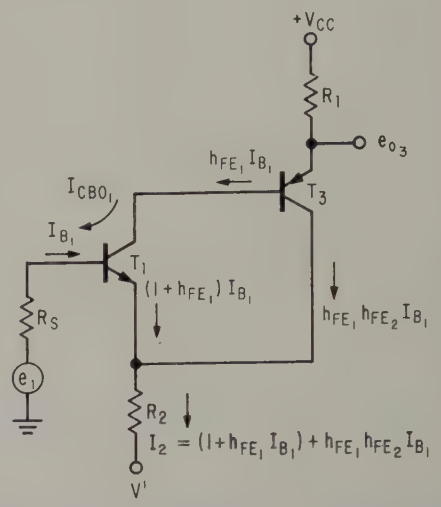

Fig. 6—Analysis by consideration of one feedback pair only.

In practice, $R_S \backsim 1\,\text{K}$, $h_{FE} \sim 40$, $R_2 \sim 200$, which gives

$R_S \ll R_2\,h_{FE_1}\,(1 + h_{FE_3})$, or in this case

R_S is 1/3 of 1 % of $R_2\,h_{FE_1}\,(1 + h_{FE_3})$.

Therefore,

$$e_{0_3} \simeq V_{CC} - \frac{R_1}{R_2}\,[e_1 - I_{CBO_1}\,R_S - V_{BE_1} - V']. \qquad (6)$$

In the same manner,

$$e_{0_4} = V_{CC} - \frac{R_1}{R_2}\,[e_2 - I_{CBO_2}\,R_S - V_{BE_2} - V'] \qquad (7)$$

Combining (6) and (7),

$$e_0 = e_{0_3} - e_{0_4} = \frac{-R_1}{R_2}\,[(e_1 - e_2) - (V_{BE_1} - V_{BE_2}) - R_S(I_{CBO_1} - I_{CBO_2})] \qquad (8)$$

which is the expression quoted in the body of the paper.

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A Survey of Semiconductor Devices and Circuits in Computers

Part 3

VELIO A. MARSOCCI*

Special Semiconductor Devices

The foregoing remarks (Parts 1 and 2) concerned the conventional transistor types and their application to computer circuitry. There also exist a variety of special devices whose characteristics permit their use in switching-type circuitry. Although these devices have not as yet found widespread use in computers as compared to conventional transistors, they will be discussed here for completeness. In the following paragraphs the unijunction transistor, devices with *pnpn*-type structures, the tunnel diode, and micromodular-type devices will be taken into consideration as a representative sample of special semiconductor elements which may find considerable application in switching circuitry. The use of semiconductors in parametric phase-locked oscillators will also be discussed.

The Unijunction Transistor

The unijunction transistor, or double-base diode, is constructed by forming a single emitting junction on a bar of *n*-type semiconductor material, the emitter and the two ends of the bar forming a three-terminal device.[4,6,19] The device is shown symbolically in the circuit drawing of *Fig 22a*. If it is assumed that with no input signal the emitter current is zero, then the semiconductor bar will have a relatively high resistance between the emitter and base 1. Therefore, the bias between the emitter and base 1 will be that portion of +E appearing across the semiconductor material of the emitter-to-base 1 region. Notice that the direction of this potential is such as to reverse-bias the emitter-to-base 1 junction. If an external potential, V_{in}, of sufficient magnitude to overcome the reverse bias due to +E, is then applied between the emitter and base 1, emitter current will exist and holes (minority carriers) will be injected into the *n*-type semiconductor material. The positive potential +E will then act to cause majority electrons to drift rapidly toward the emitter-to-base 1 junction in an attempt to neutralize the minority carriers present. The result is then an increased concentration of free charge carriers at the junction in question which then act to greatly increase the conductivity of the region near the junction. As the input potential at the emitter is increased, a point will be reached where a further increase in emitter current will be associated with a decrease of junction potential at base 1. At this point the device then exhibits a negative-resistance characteristic which lends itself to switching applications. This negative resistance is indicated by the negative slope in the unjunction transistor emitter characteristics of *Fig. 22b*.

The circuit of *Fig. 23* is an astable multivibrator[6,28] employing a single unijunction transistor. When the emitter junction becomes non-conducting, the capacitor C charges toward a positive potential through R_1 and the conducting diode D. When the potential across C overcomes the reverse bias of the emitter-to-base 1 junction, the unijunction transistor switches into conduction so that V_E drops to a value near ground potential. This action results in the diode D being reverse biased so that it cuts off, with the capacitor C then discharging through R_3. When the potential across C drops back to a value where the unijunction transistor again cuts off, the cycle repeats itself.

The stable negative-resistance characteristic of the device permits it to be employed in multivibrators,

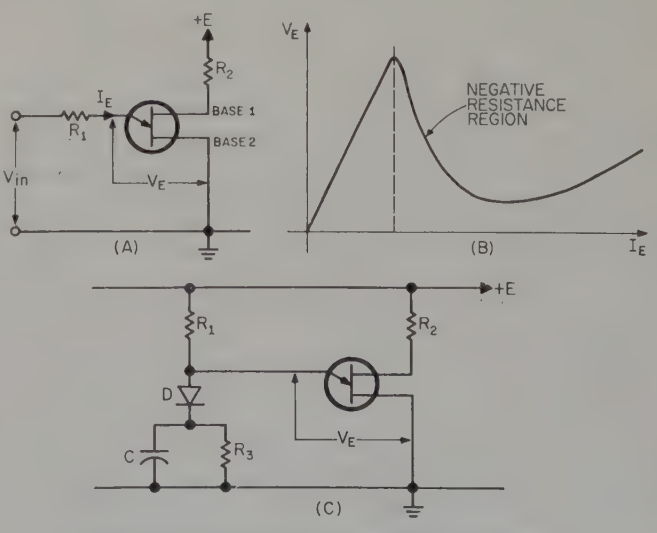

Fig. 22—Unijunction transistor circuits.

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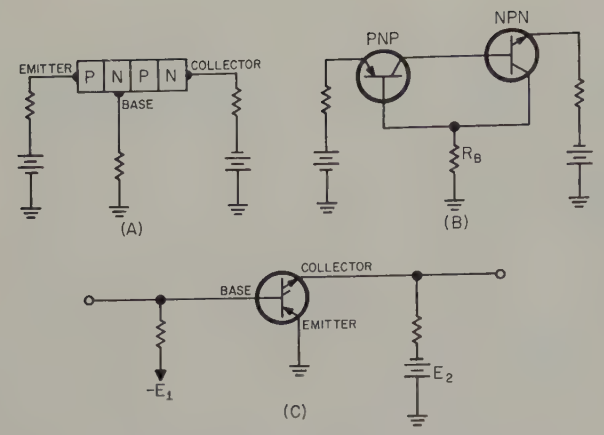

Fig. 23—PNPN transistor circuits.

sawtooth generators, pulse generators, timing circuits and as a driver in hybrid circuits in which unijunction transistors and the conventional transistors are interconnected so as to perform specific operations. The details of the operation of the unijunction transistor and the design of circuits incorporating the device are described in several articles in the literature.

PNPN Devices

It may be shown from the theory that for transistors possessing alphas greater than unity it is possible, by the use of appropriate circuit connections, to obtain negative-resistance characteristics at a given set of terminals of the resulting network. For instance, a point contact transistor, with alpha greater than unity, employed in a common base connection, exhibits a negative resistance at its input terminals if the resistance in series with the base lead is increased beyond a certain critical value. It has already been shown that a device (or circuit) with negative-resistance characteristics is useful in switching applications.

The *pnpn* (or *npnp*) transistor[4,14,25,32] is fabricated by forming a structure of four alternate layers of *n* and *p* materials. This transistor may be biased in a manner similar to that of an ordinary transistor but with the third layer left floating. The arrangement just mentioned is shown in *Fig. 23a*.

The operation of the *pnpn* transistor may be more easily described if it is considered that the first three sections act as a conventional *pnp* junction transistor in a common-base connection and the last three sections as an *npn* transistor in a common-collector connection. This analog is depicted in *Fig. 23b*.[19] Since the short-circuit current gain for the common-base connection is α, and that for the common-collector connection is $\frac{1}{1-\alpha}$, the overall current gain of the two transistors in *Fig. 23b* may have a magnitude of $\frac{\alpha}{1-\alpha}$ which represents an overall effective alpha of greater than unity with no phase reversal. It is possible, then, to obtain a negative-resistance region in the input characteristics of the circuit if R_B is made sufficiently large. If the device is used in a common-emitter configuration as shown in *Fig. 23c* the action of the circuit will be such that it can replace the flip-flop circuits which use two of the conventional transistors. That is, if the circuit is initially off, then a positive input current will trigger the circuit *on*. The *pnpn* transistor will then remain *on*, even if the input is removed, until it is switched *off* by a negative input current. Therefore, the circuit will be in one of two states, *on* or *off*, depending on the polarity of the last input current applied. This operation is similar, in a logical sense, to the flip-flop action previously described for circuits using conventional transistors. Shift registers and counters may be constructed by properly cascading several stages of the *pnpn* flip-flop circuit.

Among other four layer structures which have inherent characteristics which permit fast switching times are the *pnπn* transistor[7] and the four-layer diode. The *pnπn* transistor operates in a manner similar to the *pnpn* transistor except that a thicker base region is employed to permit the handling of larger peak voltages at the output junction. Typically, a *pnπn* transistor may be used to switch 4 ampere pulses with 20 millimicrosecond rise times.

The four-layer diode[33] is a *pnpn* structure operated in a two-terminal mode. The operation of the device may be described by reasoning similar to that employed for the *pnpn* transistor. That is, the device properties are analogous to that of a *pnp* and *npn* transistor as indicated in the discussion of the *pnpn* transistor of *Fig. 23*. An analysis of the *pnpn* structure when used as a two-terminal element (a diode) indicates that the device may be switched from one state to the other by controlling both the input voltage and current. *Fig. 24a* shows a representation of the four-layer diode and a typical set of its characteristics are indicated in *Fig. 24b*. Notice that the characteristics exhibit the region of negative resistance necessary for the bistable switching action to take place. The fast switching action and high-power handling capability of the several *pnpn* type devices discussed makes them particularly useful in switching circuits such as core drivers where high current requirements are necessary.

The *pnip* or intrinsic-barrier transistor[4] might also be mentioned here since it too consists of an additional layer of semiconductor material in the base region. However, the operation of a *pnip* transistor is

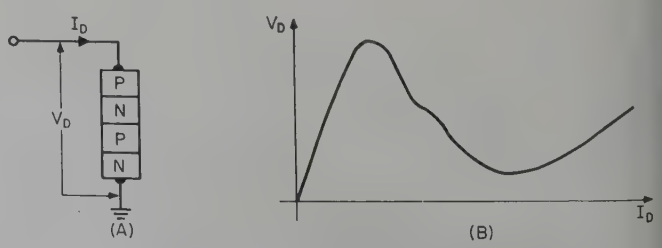

Fig. 24—A four-layer diode.

identical to that of conventional *pnp* transistors, except for the action of a layer of intrinsic semiconductor material which is placed between the *n* and *p* material at the collector junction. This intrinsic layer serves to widen the effective space-charge region at the collector junction, thus decreasing the space-charge capacity and permitting a higher breakdown voltage rating for the transistor. Therefore, an improved high-frequency response with a higher power handling capability may be realized. Circuits with pulse repetition rates of the order of 300 *mc.* are possible when utilizing intrinsic-barrier type transistors.

The Tunnel Diode

A relatively new device whose properties were first reported by Esaki,[5] and which is presently undergoing considerable investigation is the tunnel diode.[22,24,34] The diode derives its name from the quantum-mechanical tunneling effect at potential barriers. In classical theory, a particle arriving at a potential barrier such as exists at a *pn* junction can only surmount the barrier if its own energy level is greater than that presented by the barrier. However, the quantum theory gives the result that there is a non-zero probability that a particle with less than this amount of energy will penetrate the barrier and exist on the other side. The particle is said to "tunnel" through the barrier rather than pass over it. The current obtained by this effect can be made relatively large if the number of charge carriers present is large and the width of the potential barrier is made very small. These requirements are met in the tunnel diode by fabricating a *pn* diode, with an extremely thin junction region, from heavily doped semiconductor materials.

The tunnel diode's voltage-current characteristic include a negative-resistance region which permits the diode to be used to great advantage in switching applications. The conduction processes in conventional transistors are described by a concentration of minority carriers being injected into a base region, which they then traverse due to diffusion effects. The diffusion time limits the high-frequency response, and therefore the switching time, of the transistor, as has been previously described. In the case of the tunnel diode the conduction process is dependent on the majority carriers present and a signal is transmitted through the diode in much the same manner as a signal is transmitted through a metallic conductor, except that the conductor exhibits only positive resistance characteristics. The result is that the switching times associated with tunnel diodes exceed the switching times currently available from transistors by a factor of approximately 100. Also, the power requirement of a tunnel diode is about 1/100 of the power requirement of a comparable transistor. Further advantageous characteristics of the tunnel diode include temperature stability and resistance to radiation damage. At present, a major disadvantage faced by the use of tunnel diodes lies in the difficulty of designing proper coupling networks for cascaded stages of circuits employing two-terminal active devices.

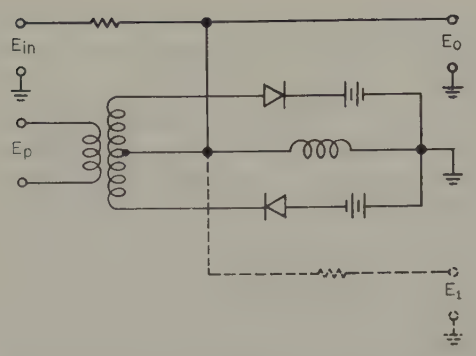

Fig. 25—Parametric phase-locked oscillator.

Parametric Phase-Locked Oscillators

The requirements for higher switching speeds has prompted several investigations concerned with the possibility of applying microwave techniques to computers. Although various methods of employing microwave devices in logic circuits have resulted from these investigations, the remarks in the present discussion will be restricted to parametric phase-locked oscillators[26] utilizing the non-linear capacitance of semiconductor diodes. The operation of the phase-locked oscillator may be described by considering a parallel-tuned circuit with a natural resonant frequency *f*. If one of the reactances in the circuit is varied at a frequency *2f* then the tuned circuit will break into oscillation at the frequency *f*. This oscillation will occur in one of two possible phases, which are 180 degrees apart, and will persist in that phase which initially occurs until some external influence causes either a phase reversal or a cessation of the oscillation entirely. The circuit can be directed into one phase or the other by applying a locking signal with frequency *f* and the desired phase at the time the oscillation is started. It is easily recognized that either of the two possible states of oscillation may be assigned the binary representation "0" and the other state assigned the representation "1". This interpretation then makes it possible to apply these parametric devices to logic systems.

It has been possible to obtain switching times between states of the order of ten cycles of the signal frequency *f*. F. Sterzer and W. R. Beam[26] have described phase-locked oscillators in strip-line form with a frequency of 2000 *mc.*, which may then possibly result in switching times of 5 millimicroseconds.

Fig. 25 shows a schematic representation of a phase-locked oscillator employing the junction capacity of reverse-biased semiconductor diodes as the variable reactance element. The locking input signal is applied at the terminals designated E_{in} and the output appears at the terminals E_o. Notice that the reverse biasing of the diodes and therefore the value of their junction capacities may be varied at the proper rate by apply-

ing a signal at the terminals E_p of frequency of $2f$. This signal is referred to as the pumping signal. Notice that the two diode branches form a balanced circuit which prevents the appearance of the pumping frequency at the output terminals. A bias signal at a desired reference phase may be injected at E_1 when the oscillator element is to be used in a gating circuit. The principle of the gating operation proceeds in the following manner. If there is no locking signal present then a time delay exists before the oscillation occurs in the unit. However, if the presence of a locking signal is applied in short periods of specified durations, then it is possible that these intervals may be adjusted so that oscillation will occur only if a locking signal is present during the short time the pumping signal is applied. Thus an output appears at E_o only if E_{in} and E_p are present during a specified time interval. Another mode of operation may be used by feeding in a biasing signal at terminals E_1. If E_{in} and E_1 are both in the "1" phase, an output will occur at E_o. If E_1 is in "1" phase and E_{in} is in "0" phase, then no output occurs since cancellation takes place between the bias and the input signals.

A variable-inductance version of the phase-locked oscillator, the parametron, has been developed in Japan. Its operating principles are similar to those previously described, except that it is the inductance in the circuit that is made to vary. Although the parametron is not dependent on semiconductors it is interesting to note that the device is in use in existing Japanese computer systems.

Microelectronics

The need for electronic circuitry with low weight and small space requirements has initiated several programs on the study of microelectronic techniques.[3, 12, 18, 20] These microelectronic circuits which have been developed employ components which form integral parts of an overall circuit structure, rather than separate circuit components wired together in a conventional manner. The complete circuit structure, usually referred to as a micromodule, might consist of an entire circuit on a single flat supporting plate, or of a combination of extremely small flat wafers, each wafer containing a circuit component. The microminiature components are fabricated on the supporting plates by the use of photographic processes, thin-film deposition techniques, conductive inks, or by some method of abrasion. The active elements, such as transistors, may be fabricated by photolithographic techniques with connections made to the active portions of the transistor structure by the use of thin-film deposition. Packing densities of 500,000 parts per cubic foot are possible with the micro-modular design arrangements. Since the circuit configurations associated with digital systems are relatively simple and are comprised of only a small number of different component types, the micro-modules have found their first great application in the area of digital computers. In general, the circuit arrangements required in a digital computer system are repetitive, representing another factor contributing to the applicability of micro-modules to digital systems. Several digital units incorporating the micro-modular design have been built and some units are available for military applications.

Another concept of micro-miniaturization techniques is represented by the fabrication of circuits in the form of a single piece of semiconductor material. Texas Instruments and RCA Laboratories have announced packing densities in excess of 25 million parts per cubic foot through the use of these solid-circuit techniques. In these so-called monolithic structures, the circuit component characteristics are obtained, for example, by utilizing the capacitance of a *pn* junction where a capacitor is needed, or by forming non-rectifying contacts to a piece of semiconductor material where a resistor is needed. Transistors and diodes are fabricated as an integral part of the structure by diffused-base techniques. The RCA Laboratories also make use of uni-polar transistors[30] as the active elements in the circuit structure.

Electronic Analog Computer Applications

The major portion of the present discussion has concerned itself with the uses of semiconductor devices in digital systems. Indeed, it is in the area of digital computers rather than analog computers that semiconductors have so far experienced the greater application. The predominating use of active devices in analog systems is to provide the gain necessary for operational amplifiers with high accuracies. In most cases, the idea of voltage as the variable of computation has been employed, and from the point of view of gain and bandwidth, it is most advantageous that the operational amplifiers be of the *d-c* type, with a voltage-summing circuit at the input. However, the inherent problem of operating point instability in *d-c* amplifiers has necessitated the inclusion of special facilities in the amplifier designs that will act to reduce amplifier drift to a minimum. In the case of vacuum-tube amplifiers the problem has been adequately met by the use of feedback arrangements and chopper-stabilization techniques. However, the low input impedance characteristic of transistors presents a more serious problem in the design of transistor feedback amplifiers since the low input impedance point, to which the feedback loop is generally returned, loads down the loop gain of the circuit and tends to degenerate the feedback action. This problem may be overcome in part by basing the computer design on a current-variable viewpoint, in which case the transistor, a current driven device, then actually possesses certain advantages when computing accuracy is considered. However, the problem associated with the operating point instability of transistors, especially when the transistors are subjected to an environment of changing temperatures, still represents a major difficulty facing the designer of transistorized high-grain *d-c* amplifiers. The drift problem

can be overcome to a great extent by the use of *a-c* amplifiers but, in general, the gains obtainable with the *a-c* amplifiers are not sufficiently high for the requirements on accuracy of general purpose analog computers.

At present, the greatest application of transistors to analog systems is in the special purpose analog computers such as airborne navigational computing systems. The specifications on the individual amplifiers in these special purpose computers are such that, in general, *a-c* amplifiers may be used. Of course, even in *a-c* amplifiers the drift in the transistor characteristics with variations in the ambient temperature still presents an appreciable problem to the amplifier designer.

The aforementioned difficulties in the design of transistorized analog computing equipment are not, however insurmountable ones. Electronics Associates, Inc., for instance, has announced the TR-10, a new desk-size transistorized general purpose analog computer with an accuracy of 0.1%. The basic computer facility includes ten chopper-stabilized *d-c* operational amplifiers with gains of 40 to 50 million. This may be compared with gains in the order of 100 million typical of *d-c* vacuum-tube amplifiers used in modern large-scale precision analog computers. The basic TR-10 unit weighs approximately 80 pounds and has a power requirement of about 60 watts. If further improvement in circuit design and in device characteristics helps to overcome the difficulties inherent in the applications of transistors to high-gain *d-c* amplifiers, then evidently, the transistor and related solid-state devices will make possible greater compactness, reduced power consumption and increased reliability in analog computer systems.

Conclusion

Several semiconductor devices and their applications in computer circuitry have been discussed. The major portion of the foregoing remarks have been devoted to the subject of conventional transistors and semiconductor diodes since these conventional elements still predominate in existing computer systems which employ semiconductor devices. The viewpoint taken in the case of digital applications has been to describe the various methods by which the switching speeds of transistor circuits may be increased by improvements in the switching characteristics of the device itself and in the design of the related circuitry. However, from the survey made of those special semiconductor devices which do not depend upon conventional transistor action for their operation, it would appear that the higher computing speeds will probably be derived from new devices such as the tunnel diode or the parametric oscillator. The growing need for compact low-weight systems with high reliability has led other research efforts into areas of entirely different circuit concepts as exemplified by the development of microminiature solid circuity.

This discussion by no means encompasses all aspects of semiconductor applications to computing systems. Several references are given which should serve as a good starting point for the reader who desires a more detailed account of semiconductor devices and their application to the computer art. (See Part 1, Dec. 1960)

Acknowledgement

The author wishes to express his gratitude to Mrs. Frances Marsocci for her able assistance in preparing this article for publication.

Diode Parametric Amplifiers

Principles and Experiments

Part 2

E. D. REED*

Experimental Negative-Resistance Parametric Amplifiers

Having established the physical principles involved in negative-resistance type parametric amplification and having discussed the variable-capacitance effect in junction diodes, we can now proceed to consider a number of experimental, low-noise amplifiers. One of the earliest amplifiers on which extensive measurements were made was designed by Uenohara for operation at 500 *mc*. The principal features of this amplifier are shown in *Fig. 8*. It consists of a simple waveguide cavity tuned to the half-pump frequency and having enough bandwidth to extend over both the signal and image bands. The loading of this cavity can be varied by an adjustable iris. A variable-capacitance

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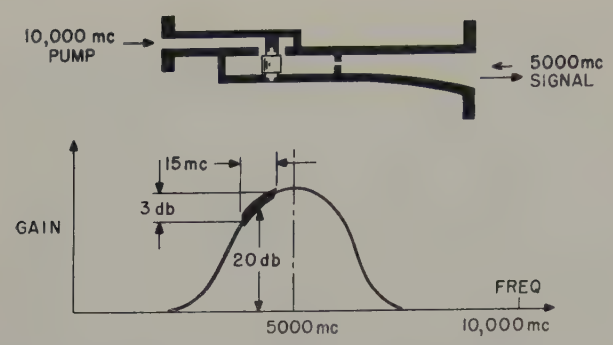


Fig. 8—Basic design features and performance of an experimental 5000-*mc* parametric amplifier due to M. Uenohara of Bell Telephone Laboratories.

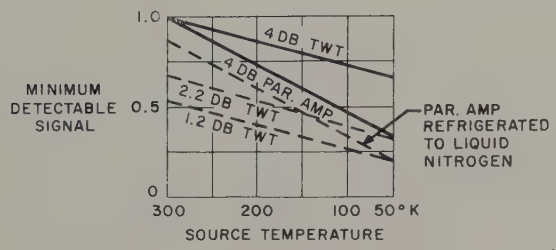


Fig. 9—Sensitivity as a function of source temperature for a traveling-wave tube and parametric amplifier both having noise figures of 4 *db* (referred to room temperature). Also shown is the further improvement due to refrigeration of diode.

diode is mounted in the center of this cavity and pump power is supplied to it through an X-band waveguide. Not shown is the ferrite circulator which completes the amplifier. The gain-frequency characteristic for this amplifier obtained with a GaAs diode is also shown in *Fig. 8*. Uenohara specifies a 15 *mc* wide signal band (represented by the thickened portion) having a midband gain of 20 *db*. For the reasons discussed previously, a 5 *mc* wide guard band is maintained between the top of the signal band and the half pump frequency.

The noise figure obtained with this amplifier is 4 *db* for "single sideband reception," i.e., for the condition where signal is introduced in the signal band only but noise enters the amplifier both in the signal and in the image band. However, in comparing a parametric amplifier having a 4 *db* noise figure with, say, a 4 *db* noise figure traveling wave tube it is important to bear in mind that in the case of the parametric amplifier a smaller fraction of the total noise output is due to noise generated within the amplifier. This also means that as the source temperature is decreased or, in practice, as we point the amplifier at the cold sky, image noise becomes negligible and the parametric amplifier then exhibits noise performance superior to that of a traveling wave amplifier of identical noise figure. This is illustrated in *Fig. 9*, which shows the minimum detectable signal as a function of source temperature for a 4 *db* traveling wave tube and a 4 *db* parametric amplifier. The minimum detectable signal has been normalized with respect to its value at room temperature. Naturally, both the *TWT* and the parametric amplifier start out with the same sensitivity but as the source temperature decreases—and with it, the image noise contribution—the sensitivity of the parametric amplifier increases faster than that of the *TWT*. At a source temperature of 50°K, the parametric amplifier is about twice as sensitive as the *TWT*. As a matter of fact, a traveling-wave tube would require a noise figure of 2.2 *db* in order to exhibit at this source temperature the same sensitivity as a 4 *db* parametric amplifier. For the case where the signal itself is noise as in radio astronomy, we may introduce this noise signal in both the signal and image band, as was pointed out earlier, and thereby obtain a 3 *db* advantage in noise performance. This would make the sensitivity of a 4 *db* noise figure parametric amplifier equivalent to that of a *TWT* having a figure of 1 *db*. The fact that we have now mentioned three different equivalent noise figures in connection with the same amplifier namely 4, 2.2 and 1 *db* may seem confusing. It is true, however, that there is no single number which fully describes the noise performance of this amplifier under all conditions. For single sideband reception from a room temperature source its sensitivity is equal to that of a 4 *db TWT*. For single sideband reception from a cold source such as the sky, its sensitivity equals that of a 2.2 *db TWT* and for the reception of radio astronomy signals the noise figure is equivalent to a 1 *db TWT*.

All the results given so far are for the case where the amplifier itself is maintained at room temperature but where the external image noise is eliminated by pointing the antenna at the cold sky. We may obtain further noise improvements by refrigerating the amplifier itself and thereby reducing the internal noise due to the diode series resistance. The dotted lines in *Fig. 8* show the result of refrigerating the amplifier proper to liquid nitrogen temperature, i.e., to about 75°K. We see that the single sideband performance of this refrigerated amplifier when looking into the cold sky is equivalent to a 1.2 *db* noise figure *TWT*. For radio astronomy signals the refrigerated amplifier is equivalent to a 0.3 *db* noise figure *TWT*.

Uenohara was also able to obtain low noise amplification at 11,000 *mc*. Using a GaAs diode in a waveguide environment scaled from that described above he obtained a single-sideband noise figure (at room temperature) of 6.5 *db*. B. C. de Loach, also of Bell Labs., used a GaAs diode to obtain amplification at 30,000 *mc*. This is the highest frequency reported to date for a parametric amplifier.

Parametric amplifiers similar in concept and execution but operating at different frequencies have been described by workers at Hughes Research Laboratories and Stanford University.

Broadbanding Techniques

One basic shortcoming of the type of negative-re-

sistance amplifier which employs a single diode in a simple resonant cavity, is its lack of adequate bandwidth. Attempts to overcome this limitation have followed two separate and distinct paths, both of which have led to interesting and useful results. The earlier of the two broadbanding schemes makes use of large numbers of diodes in iterated structures while the more recent method combines special broadband circuitry with a single diode.

The principle underlying the operation of the iterated amplifier involves elimination of band-limiting resonant circuits and operation of the diode in a truly broadband environment. Since this greatly reduces the gain obtainable from an individual diode we must resort to the use of large numbers of diodes in suitable arrays in order to build up the desired over-all gain. A very useful property of this iterated amplifier, in addition to its bandwidth, is the unidirectionality of its gain, i.e., this amplifier has gain in the forward direction and no gain in the reverse direction.

To illustrate the principles involved here we shall make the following simplifying assumptions:

(1) The signal frequency is equal to exactly half the pump frequency,
(2) the signal and pump waves propagate through the structure with the same phase velocity, and
(3) we can choose any arbitrary phase relation between the signal and pump waves.

Let the drawing at the top of *Fig. 10* represent a transmission line, which may be a modified waveguide or coaxial line, and let the vertical lines represent the positions of diodes mounted across this line. We shall space these diodes a quarter wavelength apart at the pump wavelength. The reason for this spacing will become clear when we consider the reverse gain of this amplifier. As far as forward gain is concerned, the spacing of these diodes is immaterial. Let the sine curves in *Fig. 10* represent snapshot pictures of the electric-field distribution in the transmission line, the solid curves due to the signal and the dashed curves due to the pump. As both these sine waves move through the transmission line in the same direction, say to the right, with the same phase velocity, it is clear that interaction between pump and signal will take place with the same phase relation at each successive diode. Hence, if this phase relation is chosen to be favorable for any one diode, it will be equally favorable for all other diodes and the signal wave will grow exponentially as it progresses along the structure. Such a favorable phase relation between the signal and pump wave is shown at the top of *Fig. 10*.

What happens, however, when the pump and signal waves propagate in opposite directions? In the sequences, corresponding to instants of time t_1, t_2, and t_3, we see the signal wave traveling from right to left, i.e., in the reverse direction, while the pump wave continues from left to right. If we now examine, by inspection of *Fig. 10*, what any two adjacent diodes, such as diodes **A** and **B**, will see as a function of time, we find that diode **A** will see the pump and signal in-

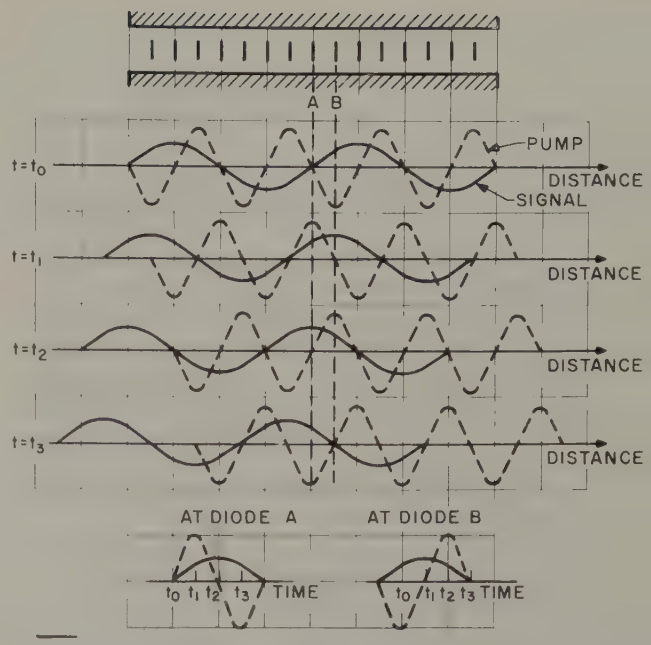


Fig. 10—Illustration of the operation of an iterated, broad-band amplifier and the production of non-reciprorocal gain.

teract with the correct phase relationship for negative-resistance generation while diode **B** will not. In fact, diode **B** will absorb power. Plots of the interaction of signal and pump at diode locations **A** and **B** are given at the bottom of *Fig. 10*. The plot for diode **A** may be seen to be identical to that shown in *Fig. 1* and to result in maximum energy transfer from pump to signal. For the situation, then, when pump and signal propagate in opposite directions, half the diodes will amplify and the other half will absorb power, resulting in a net reverse gain of unity. This produces gain stability superior to that of the cavity-type negative-resistance amplifier but not nearly as good as that of, say, a traveling-wave tube or traveling-wave maser. In both these devices, the reverse loss exceeds the forward gain.

In the more general case, when the signal frequency differs from half the pump frequency, an idler wave of frequency, *p-s*, will, again be generated and provision must now be made for the propagation of this wave along with the signal and pump waves. The phase velocities of these waves must be adjusted so that their phase constants satisfy a condition stipulated by Tien and Suhl which requires that $\beta_s + \beta_{p-s} = \beta_p$.

An iterated amplifier employing the principles just described was built by R. S. Engelbrecht of Bell Telephone Laboratories for operation at 600 *mc*. His amplifier, may be considered to consist of two transmission lines, electrically uncoupled but occupying the same space. One of these carries the pump energy and the other the signal. In the cross section of *Fig. 11* the electric field configuration due to the pump is represented by solid lines and that due the signal by the dashed lines. Variable capacitance diodes, two per stage, are placed into a region where the pump and

signal fields are parallel (or antiparallel) and their polarities are chosen such that their capacitances go up and down together under the influence of the pump. Compliance with the Tien Suhl phase-condition is achieved by adjustment of the trimming capacitors which, as may be seen in *Fig. 11,* are placed in a region where they can only interact with the pump field. Using 16 pairs of diodes in one amplifier, Engelbrecht obtained these results:

(1) A usable bandwidth of 100 *mc* or roughly 20% for single sideband reception.
(2) An average gain over this band of 9 *db*.
(3) Reverse gain ranging from —2 to 0 *db* and
(4) Noise figure of 3.5 *db* (for cold sky reception the sensitivity is equivalent to a 2.5 *db* noise factor *TWT*.).

The comparatively low gain of this amplifier should not be interpreted as a basic limitation of the device but rather the result of stability considerations based on the particular values of input and output mismatch between which the amplifier was required to operate.

In an attempt to improve the stability of the negative-resistance iterated amplifier still further, workers at Hughes Research Laboratories have been experimenting with the use of built-in nonreciprocal ferrite elements. The test section which gave rise to the results shown in *Fig. 12* used a signal line consisting of four transmission type cavities each containing one diode and coupled by means of ferrite loaded irises. Pump power was fed to each diode separately with phase individually adjusted for optimum interaction. The experimental results indicate broadband performance, about 150 *mc* for single sideband reception,

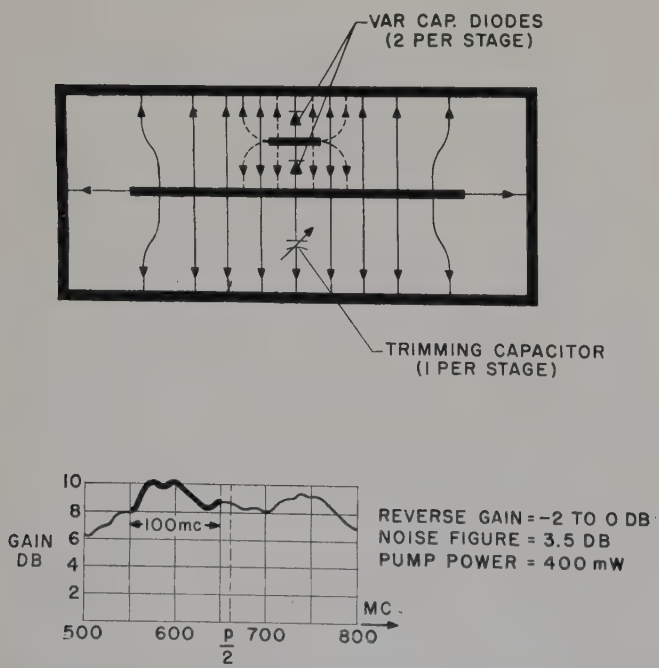


Fig. 11—Basic features and performance curves of an iterated amplifier due to R. Engelbrecht of Bell Telephone Laboratories. The results shown were obtained with 16 pairs of diodes.

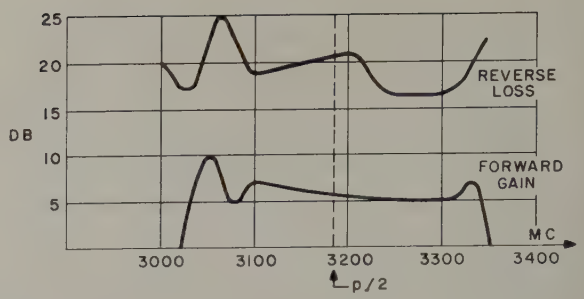


Fig. 12—Reverse loss exceeds forward gain and hence gives unconditional stability in an early experimental iterated amplifier incorporating non-reciprocal ferrite loss elements. Due to Currie, Weglein et al. of Hughes Research Laboratories.

and, since the reverse loss over this band greatly exceeds the forward gain, unconditional stability.

An obvious and serious disadvantage of the Bell Labs and Hughes iterated amplifiers is their lavish need for high-quality, highly identical diodes. To circumvent this disadvantage, H. Seidel and coworkers at Bell Telephone Labs have been experimenting with a broadbanding technique in which a single diode interacts with suitable filter circuitry. A somewhat similar technique has been used in the past by the author to increase the electronic tuning range of reflex klystrons. The principles involved in this broadbanding scheme may be understood from the equivalent circuit of the negative-resistance, parametric amplifier shown in *Fig. 13*. Here, we see a transmission line of characteristic conductance, G_0, terminated in a cavity across which appears the negative conductance, $-|G|$, generated by the pumped capacitance. Compared to the frequency sensitivity of the cavity, the negative conductance varies only slowly with frequency. It reaches a maximum at the half-pump frequency and drops to zero both at zero frequency and at the pump frequency. We will therefore, consider $-|G|$ to be invariant with frequency. Voltage gain is given by:

$$\text{Voltage Gain} \equiv \frac{V_{REFL.}}{V_{INCID.}} = \frac{G_0 - Y_L}{G_0 + Y_L}$$

but

$$Y_L = -|G| + jB$$

hence

$$\text{Voltage Gain} = \frac{G_0 + |G| - jB}{G_0 - |G| + jB}$$

At midband, $B = 0$, hence for high gain, $|G|$ must approximately equal G_0. The real part of the numerator is therefore much greater than that of the denominator. This, in turn, makes the numerator so much less frequency dependent than the denominator that it may, for our purposes, be regarded as a constant. Thus,

$$\text{Voltage Gain} = \frac{K}{(G_0 - |G|) + jB}$$

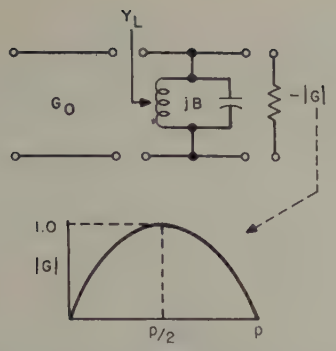


Fig. 13—Equivalent circuit of a negative resistance amplifier using a single diode in simple cavity. Compared to the cavity, the negative conductance is seen to be a slowly varying function of frequency.

In words, gain is inversely proportional to the input admittance or directly proportional to the input impedance of a simple resonant circuit having a shunt conductance $G_0 - |G|$. This suggests that broadbanding techniques involving the use of multiple coupled cavities would be applicable here.

Using three coupled cavities in the arrangement shown in *Fig. 14*, Seidel and his coworkers at Bell Telephone Labs have been able to confirm the validity of these ideas. They obtained a useful bandwidth of about 100 *mc* centered around 450 *mc*, i.e., a better than 20% bandwidth. Since this amplifier is completely bidirectional, it requires a broadband circulator having excellent matches to ensure stable operation. Such circulators are presently not available in this frequency range. The gain curve shown in *Fig. 14* was obtained with a directional coupler. It therefore indicates what *could* be done with a circulator rather than what *has* actually been achieved in a stable amplifier.

The Up-Conversion Amplifier

The up-conversion amplifier, or up-converter, is the second major type of variable-capacitance amplifier. It differs from the negative-resistance amplifier in these respects:

(1) The amplified signal is extracted at the upper-sideband frequency, $p + s$, rather than the lower-sideband, $p - s$, which is used in the negative resistance amplifier.

(2) In the up-converter, gain is proportional to the output-to-input frequency ratio, $(p + s)/s$. Hence, to achieve reasonable gain, the pump frequency must be many times greater than the signal frequency, whereas a ratio of only two was required for the negative-resistance amplifier. This requirement for a large ratio of pump to signal frequency has restricted experimental up-converter work to signal frequencies in the below-1000 *mc* band.

(3) In the up-converter, the signal frequency is inevitably shifted in the amplification process while in the negative-resistance amplifier we had the choice of using the amplified output either at the signal frequency or at the lower sideband frequency.

(4) The up-converter is a true two-port amplifier having unconditional stability whereas the negative-resistance amplifier, being a single-port amplifier, requires, for stable operation, exceptionally good matches plus auxiliary instrumentation in the form of circulators, isolators or built-in ferrite elements.

While the operation of the negative-resistance amplifier could be explained with a particularly simple model, namely the mechanical pumping of a capacitor, a similarly pleasing model for the up-converter has not come to the attention of the author. Instead, this topic will be introduced by considering the fundamental power relation for a nonlinear (and lossless) reactance as expressed in a theorem by Manley and Rowe. This simple yet very powerful theorem states that when a strong pump of frequency, p, and a weak signal of frequency, s, are simultaneously impressed on a nonlinear reactance, and if we consider only the signal and the two lowest sidebands, $p - s$ and $p + s$, that is, ignore all higher-order modulation products, then

$$\frac{P_s}{s} + \frac{P_{p+s}}{p+s} - \frac{P_{p-s}}{p-s} = 0$$

where P_s, P_{p+s} and P_{p-s} are the powers at the frequencies s, $p + s$ and $p - s$. A positive value of P denotes net power leaving the amplifier, and a negative value denotes power absorbed by the amplifier. In the negative-resistance amplifier we assume that our circuit does not respond to the upper sideband, $p + s$, hence the middle term above is zero and the Manley-

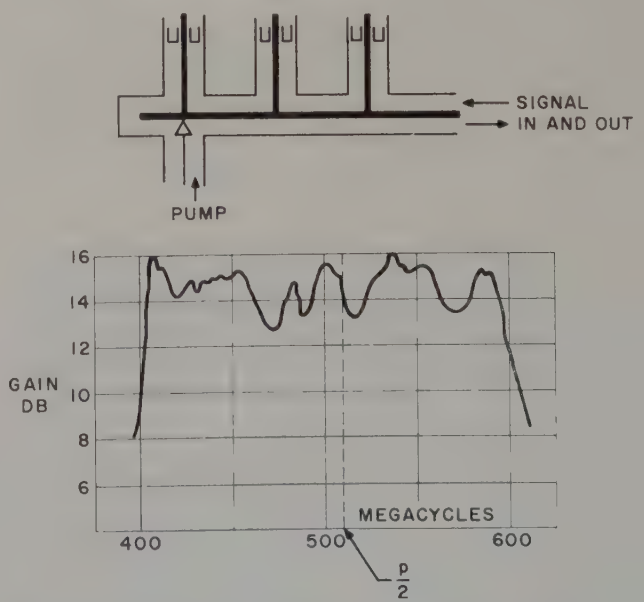
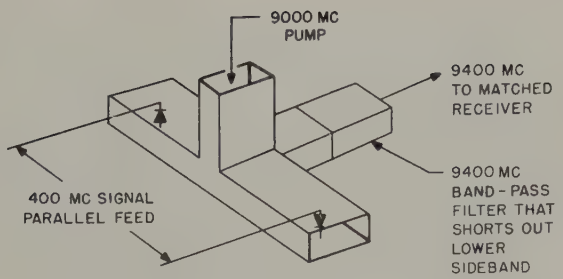


Fig. 14—Schematic representation and performance of a negative-resistance amplifier using a single diode and 3 coupled cavities. Due to H. Seidel et al. of Bell Telephone Laboratories.



PERFORMANCE OF UP-CONVERTER	
GAIN	11db
BANDWIDTH	22 MC
NOISE FIGURE	0.7 db (50°K)

Fig. 15—Basic outline and performance data of a 400-*mc* up-conversion amplifier due to P. P. Lombardo of Airborne Instruments Laboratories.

Rowe relation describing this case becomes,

$$\frac{P_s}{s} = \frac{P_{p-s}}{p-s}.$$

We can see that, in order to have amplification at the signal frequency, s, that is, more power at s leaving the amplifier than entering it, P_s from our previous definition must be positive. This, in turn, means that P_{p-s} is also positive, showing that if amplified signal power leaves the amplifier, we must also have image power or lower-sideband power leave the amplifier. Incidentally, by rearranging the above relation as

$$P_{p-s} = \frac{p-s}{s} P_s$$

we see that the lower sideband exceeds the signal power by the frequency ratio $(p-s)/s$. We shall come back to this later.

In the up-converter, the circuit responds to the signal and the upper sideband and *not* to the lower sideband. Setting $P_{p-s} = 0$ in the Manley-Rowe relation, we obtain

$$P_{p+s} = \frac{p+s}{s}(-P_s)$$

Here the two powers are of opposite sign. Hence, if we want power out at one frequency, we must put power in at the other. In particular, if we inject power at frequency s, that is, make P_s negative, we can extract $(p+s)/s$ times as much power at the frequency, $p+s$.

An experimental up-conversion amplifier built by Airborne Instruments Laboratories is shown in outline in *Fig. 15*. A variable-capacitance diode is mounted in each of the collinear arms of a hybrid junction. The diodes are mounted with reversed polarities so that their capacitances vary in phase when they are excited by the out-of-phase pump signals coming from the E-arm. The signal is impressed in-phase on both diodes resulting in two amplified signals at the upper-sideband frequency. These in-phase signals are recombined at the center of the junction and emerge from the H-arm. The hybrid junction thus serves to provide individual ports for the input signal, pump and output. To ensure operation as a true up-converter, i.e., to eliminate any negative-resistance gain, the output waveguide is equipped with a filter designed to pass the upper sideband only and to place a short in the plane of the diodes at the lower-sideband frequency. The up-conversion amplifier by itself has a noise figure of only 0.7 *db*. Because of the limited gain of the amplifier (11 *db*), the noise contribution from the subsequent stage cannot be neglected. It will tend to raise the over-all system noise figure to a value higher than that of the up-converter stage.

Lower Sideband Up-Converter

This is the third and last type of parametric amplifier to be described here. A comparison of the frequencies involved in this type of operation with those involved in the negative-resistance and up-conversion amplifiers is given in *Fig. 16*. The lower sideband up-converter is, essentially, a negative-resistance amplifier differing, however, from the type we considered earlier in two respects:

(1) The useful output is no longer at the signal frequency but rather at the lower sideband or image frequency, that is, at a higher frequency.

(2) The signal frequency is no longer close to half the pump but, rather, very much lower. This makes possible the introduction of up-conversion gain in addition to the negative resistance gain which is inherent in lower-sideband operation.

This amplifier has advantages both with respect to the pure negative-resistance type as well as the pure up-converter. Compared to the former, it offers improved stability since for a given over-all gain only

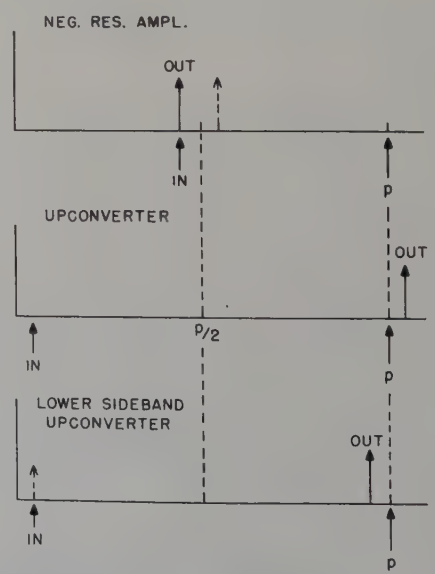


Fig. 16—Comparison of frequencies used in the three basic types of variable-capacitance amplifiers.

part of this gain is derived from negative-resistance gain with the rest coming from stable up-conversion gain. Compared to the pure up-converter, it offers the advantage that the available gain is no longer limited by the ratio of output to input frequency.

There is also a noise advantage in this operation. We saw before, in the case of the ideal negative-resistance amplifier, that image noise effectively doubled the noise in the signal channel and thereby put a 3 *db* floor under the noise figure. In the lower sideband up-converter the effect of image noise is much less serious. Again, the noise in the output channel stems from noise introduced at the signal and image channels but while the signal-band noise is amplified both by negative-resistance and up-conversion gain, the image noise is amplified by a smaller amount, namely, negative-resistance gain only.

Fig. 17 shows the basic features of a lower-sideband up-converter developed at the Bell Telephone Laboratories by H. Seidel and coworkers for application in a scatter-propagation system. This amplifier has achieved an over-all system noise figure of about 1.5 *db*. Its gain and bandwidth are 20 *db* and 20 *mc* respectively.

Noise Performance Comparison: Tubes, Parametric Amplifiers and Masers.

In *Fig. 18* we see a performance comparison for the three principal types of low-noise microwave amplifiers: vacuum tubes, parametric amplifiers and masers. For convenience, noise performance is expressed both as Noise Figure in *db* and as Equivalent Noise Temperature in °K. The top curve shows the best noise performance obtained with experimental vacuum tube amplifiers. At 500 *mc* a closed-spaced planar triode developed by Von Ohlsen at the Bell Laboratories has yielded a noise figure of 2.5 *db*. At 3000 *mc*, noise figures of 3.5 *db* have been obtained by Currie of Hughes

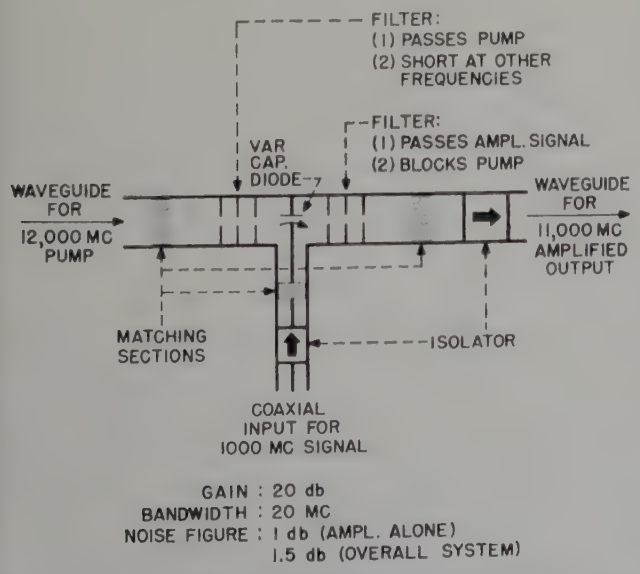


Fig. 17—Lower sideband up-converter for use in a scatter propagation system. Due to H. Seidel et al. of Bell Telephone Laboratories.

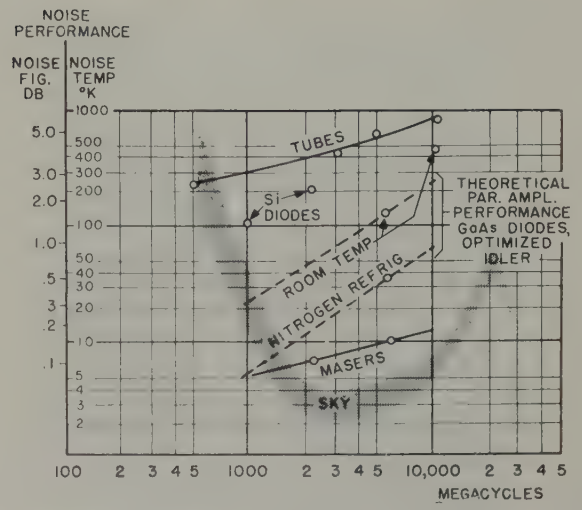


Fig. 18—Noise performance comparison of vacuum tubes, parametric amplifiers, and masers.

Aircraft Company in a backward-wave amplifier and also by St. John and Caulton of the Bell Laboratories in a traveling-wave tube. At X-band, noise figures of about 6 *db* have been obtained with traveling-wave tubes both at Stanford University and at the Bell Laboratories. This listing of low-noise tube performance is by no means complete but indicative of the present state of the art.

Maser noise performance is illustrated by the lowest curve in *Fig. 18*. The two experimental points on this curve represent measurements made at Bell Laboratories by Scovil and DeGrasse on ruby traveling-wave masers.

Parametric amplifier noise performance lies in the general region between low noise tubes and masers. It is represented by two dashed lines giving computed performance and by five experimental points. The computed curves are based on measured parameters of GaAs diodes and on the assumption of optimized treatment of idler noise. This optimization may take the form either of using a sufficiently high pump frequency or of refrigerating the idler load. The GaAs diode itself is assumed to be at room temperature in the upper curve and at liquid nitrogen temperature in the lower one.

The two experimental points on the left show results obtained with silicon junction diodes in negative-resistance up-converters at 1000 and 2000 *mc* respectively. The remaining three experimental points in *Fig. 18* pertain to single side-band performance obtained in negative resistance amplifiers employing GaAs diodes both at room and liquid nitrogen temperatures.

Finally, *Fig. 18* shows the variation of sky noise with frequency. This noise has a minimum in the range from 1500 to 10,000 *mc*. Beyond this frequency band, sky noise climbs rapidly due to oxygen and water vapor absorption while below it, the increasing sky temperature is due to galactic noise. The width of the sky noise plot indicates the effect of antenna angle,

with the lower bound corresponding to a vertical antenna angle and the upper one to an angle of 60° with the vertical. For larger angles, the noise temperature of the sky increases rapidly and reaches about 200°K for an antenna pointed at the horizon.

Thus we see that as far as noise temperature is concerned, tubes are most closely matched to the sky in the several-hundred megacycle range, parametric amplifiers in the *uhf* and low microwave region and masers in the mid-microwave range. Masers, therefore, are most suited for applications in this latter frequency range providing the antenna angle does not greatly exceed 60° and providing, also, the circuit elements preceding the maser in the receiver chain have very low loss. This then, makes the maser a strong contender for applications involving the reception of weak microwave signals which traverse the atmosphere at a steep angle. Such signals are encountered in space and satellite communication, radio astronomy, and missile defense. In the below-1000 *mc* range masers are ruled out because of the high sky noise temperature. Above 15,000 *mc*, where sky noise is also high, masers are of interest primarily because of the absence of economically competing low noise amplifiers.

Eliminating these special applications for which masers appear peculiarly suited, this leaves parametric amplifiers and low-noise tubes in competition for the majority of microwave applications including radar and radio relay communications. Here the parametric amplifier offers the important advantage of superior noise performance, while the traveling wave tube—in part for basic reasons and in part because of its more advanced state of development—offers simplicity (no microwave pump), stability, bandwidth, and the capacity to handle large overloads. In the *uhf* and low microwave range, i.e., at frequencies where the pump signal could in time be generated by transistors, the diode parametric amplifier holds out hope for an all-solid-state low-noise receiver. In addition to low noise, such a receiver would offer features of particular importance for satellite borne applications, namely, the potential for long life and very low power drain.

Acknowledgement

The author wishes to thank his many colleagues, both within and outside Bell Telephone Laboratories for permitting him to report on their work.

A Review of the Transistor Chopper*

W. S. MASSEY†

THE SEARCH FOR LOW LEVEL modulators for converting *dc* to *ac* has led to a wide variety of physical and even chemical devices. Although the electro-mechanical chopper has never been surpassed in its ability to penetrate to low levels (a few microvolts or less) a natural mistrust of mechanical devices has spurred the search for a "solid state" modulator. Despite continued improvement in the electromechanical chopper or contact modulator which enables it to perform during shock, acceleration and vibration with a life expectancy of 4,000 hours, the appeal in a solid state device has led to a host of modulators among which are the photo, capacitor, magnetic, diode, vacuum tube and transistor modulators. The latter is by far the strongest contender. Its noise level along with that of the magnetic modulator is the lowest available among all solid state modulators.

In its most basic form, a transistor chopper would appear as shown in *Fig. 1*. The transistor is alternately biased *on* (to saturation) and *off* by the drive. This permits current flow from the signal source to the load to be interrupted at the frequency of the drive.

With this simple arrangement, several undesirable characteristics would be obtained. When the transistor is biased *on*, even fully saturated, a small potential difference exists between its collector and emitter. This voltage drop (which ranges from about one to one-hundred millivolts for different transistors) will come and go as the transistor is alternately turned on and off. Even in the case that the signal voltage is zero, this voltage will be present and will be coupled to the load where it will appear as an offset voltage

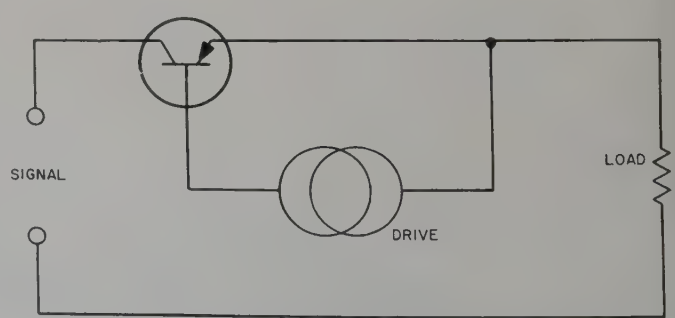


Fig. 1—Basic transistor chopper circuit, *spst*.

*This article originally appeared in the *Airpax Technical Journal* and is reprinted here through the courtesy of Airpax Electronics Inc., Seminole Division, Ft. Lauderdale, Florida.

†Airpax Electronics Inc., Seminole Division
Ft. Lauderdale, Florida.

of substantial magnitude. Some examples of this are shown for both sine and square wave drive voltages in *Fig. 2.**

Fortunately, it has been found that in most transistors, a lower saturation voltage drop may be obtained by using the collector of the transistor for the emitter and the emitter for the collector. This inverted connection gives as much as a ten-fold improvement. *Fig. 3* gives some idea of the amount of improvement which is possible. Notice that the scale is the same as in *Fig. 2*.

A more effective remedy for this offset voltage may take the form shown in either *Fig. 4* or *6*. In *Fig. 4* the transistors are both on at the same time with their saturation voltage drops in opposition. If the transistors are matched for equal voltage drops there is nearly complete cancellation. In *Fig. 5a* two transistors are shown in the normal connection (emitter for emitter, collector for collector) with the same scale as *Fig. 2* for comparison. In *Fig. 5b* the sensitivity has been increased by a factor of 10 to permit closer examination of the same wave. Still further improvement is possible by using the inverted connection.

In *Fig. 6* the transistors are back to back and driven out of phase so when one is on, the other is off. The result is that the voltage drop of one or the other transistor is alternately coupled to the load with each transistor on for nearly one-half cycle. If the transistors are matched for equal drops, the result is a constant *dc* coupled to the load with no offset component. The results of this approach are shown in *Fig. 7*. In both cases the *dc* component is evident. Here the transistors were both connected inverted, but the normal connection would give similar results except that both the ripple and *dc* component would be greater.

Another characteristic of the chopper in *Fig. 1* which may be troublesome, is the result of the collector cutoff current of the transistor. This small current will pass through the load and, where the load impedance is high, can produce a substantial offset voltage. This problem can be reduced by using the circuits shown in *Figs. 4* and *6*, if the transistors are *also* matched for equal cutoff currents. In *Fig. 4* the currents occur at the same time but in opposite directions and tend to cancel. In *Fig. 6* the transistors take turns in supplying this current to the load, thereby cancelling any offset which might be caused.

Two more factors may be helpful. Since the cutoff current has a high source impedance and is, therefore, independent of impedances external to the transistor, the voltage drop produced may be made small by making the load impedance as small as practical. Also, at any given temperature, the cutoff current of a silicon transistor will be much less than its germanium counterpart. The effect of load impedance in the circuit of *Fig. 4* is demonstrated in *Fig. 8*.

*In the following photographs, the top trace is the drive voltage, 6.3 volts rms, 400 cps, either a sine wave or square wave as shown. It is shown to provide a phase comparison. All scale calibrations are per major division.

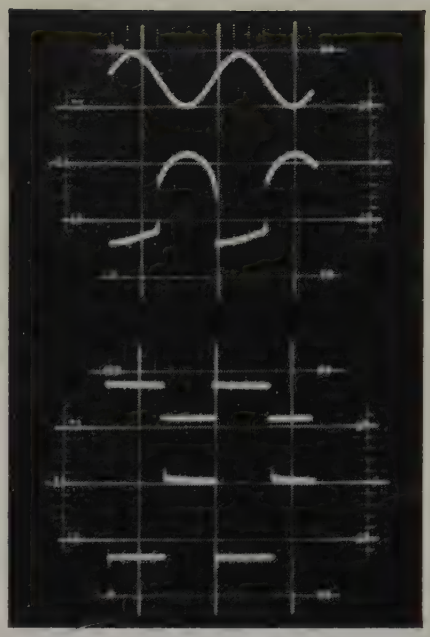


Fig. 2—(a) Noise voltage. Circuit: Fig. 1. Scale: 20 *mv*. Load: 1,000 ohms. (b) Noise voltage. Circuit: Fig. 1. Scale: 20 *mv*. Load: 1,000 ohms.

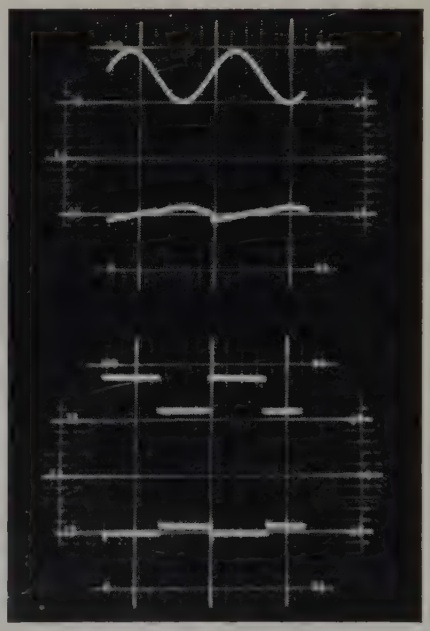


Fig. 3—(a) Noise voltage. Circuit: Fig. 1 (collector and emitter interchanged). Scale: 20 *mv*. Load: 1,000 Ohms. (b) Noise voltage. Circuit: Fig. 1 (collector and emitter interchanged). Scale: 20 *mv*. Load: 1,000 ohms.

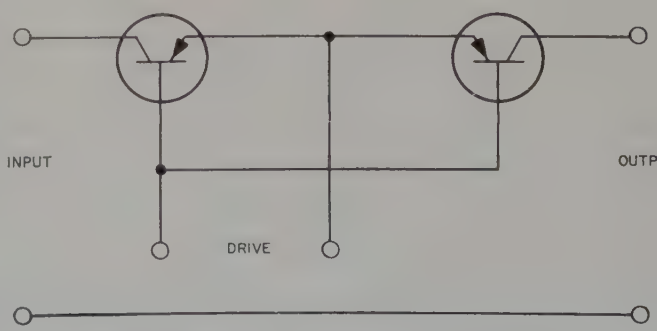


Fig. 4—Bilateral transistor chopper *spst*.

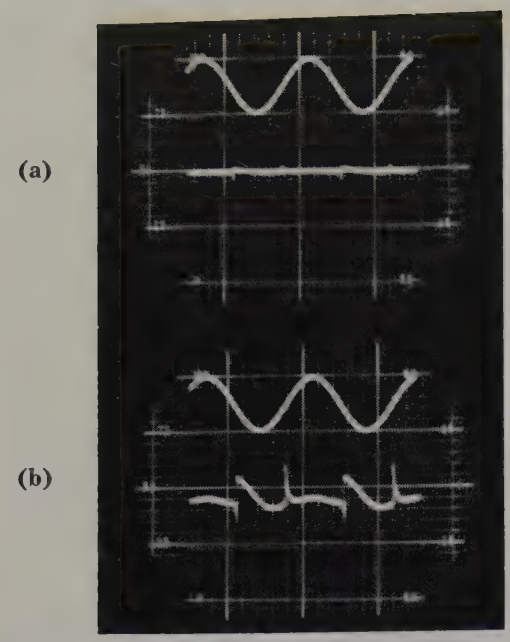


Fig. 5—(a) Noise voltage. Circuit: Fig. 4. Scale: 20 *mv.* Load: 1,000 ohms. (b) Noise voltage. Circuit: Fig. 4. Scale: 2 *mv.* Load: 1,000 ohms.

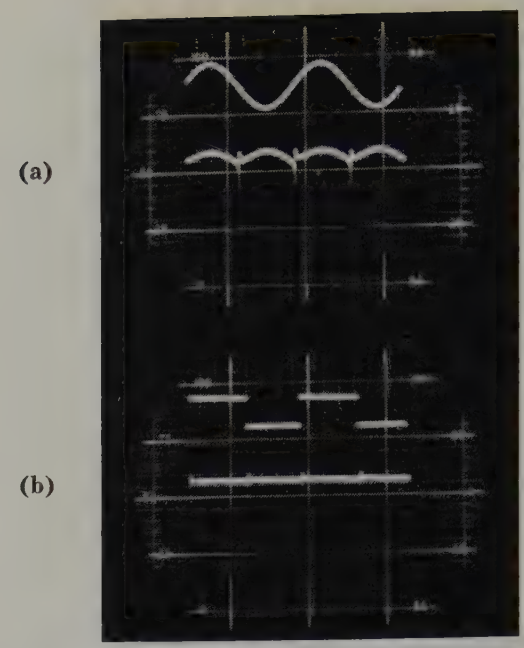


Fig. 7—(a) Noise voltage. Circuit: Fig. 6 (collector and emitter interchanged). Scale: 2 *mv.* Load: 10,000 ohms. (b) Noise voltage. Circuit: Fig. 6 (collector and emitter interchanged). Scale: 2 *mv.* Load: 10,000 ohms.

In both *Figs. 1* and *6*, it is apparent that switching action may be accomplished easily with signals of one polarity (the polarity which would tend to make the collector more negative than the emitter). The opposite polarity of signal may also be switched provided the reverse bias voltage applied from emitter to base exceeds the maximum signal voltage to be controlled. In this situation, a square wave is desirable. The difficulty which arises when a sine wave drive voltage is used with these circuits is illustrated in *Fig. 9*. Here the output waveform is distorted as a result of the time required for the drive voltage to reach a value which overrides the signal. If a square wave is used, this distortion is reduced as in *Fig. 9b*.

In *Fig. 4* this would present no problem since for either signal polarity, one transistor would be cut off as soon as its emitter-base junction was reverse biased. With this configuration, signal voltages as large as 100 volts may be controlled with drive voltages as small as one volt.

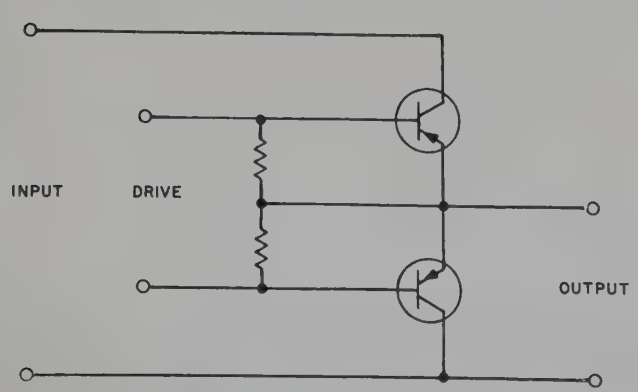


Fig. 6—Series-shunt transistor chopper *spst.*

The linearity using arrangements of the form of *Fig. 4* is limited, principally by offset and noise. Offset can be adjusted out elsewhere in the system, and in most cases, signal to noise ratios as low as unity still give good results since the noise is a constant. One more characteristic which should be considered is the effect of junction capacitance. This capacitance provides an undesired means of coupling drive voltage into the load. Since the capacitance is voltage dependent and is maximum at the instant the transistor is being turned off, a spike of considerable amplitude may result. This spike can be suppressed by limiting the amplifier bandwidth (filtering). There is also a quadrature component of the drive voltage which reaches the load. This produces no offset in itself, but makes a noise component which may have a masking effect on small signals. With such a small capacitance (i.e., high reactance) the noise produced will be proportional to the load impedance and to the drive frequency used. *Fig. 10* shows the effect of load impedance. (Note the difference in scales.) Where small signals must be considered, this effect becomes a limitation at much lower frequencies than those related to actual switching time.

While these characteristics may seem to restrict the usefulness of transistor choppers, their advantages may exceed their limitations. Since they use stationary parts, they are not disturbed by extremely high shock, vibration or acceleration. They perform with very small lag so they operate in phase with their drive voltage, avoiding external correcting networks. Both phase angle and dwell time are nearly independent of drive frequency, voltage, and temperature.

Fig. 11 shows a typical application using the techniques of *Fig. 4*. Two pairs of bilateral switching tran-

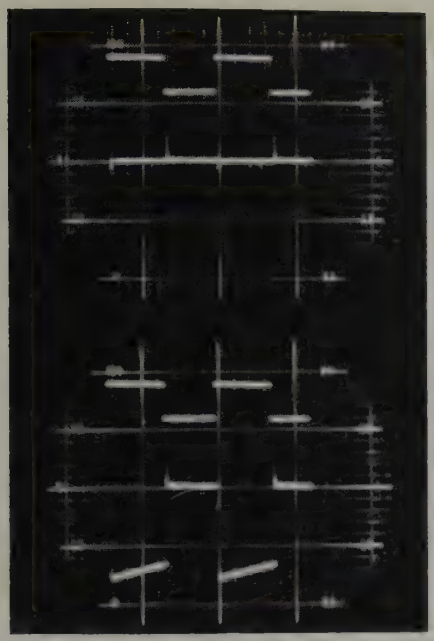


Fig. 8—(a) Noise voltage. Circuit: Fig. 4. Scale: 2 *mv*. Load: 100 Ohms. (b) Noise voltage. Circuit: Fig. 4. Scale: 2 *mv*. Load: 10,000 ohms.

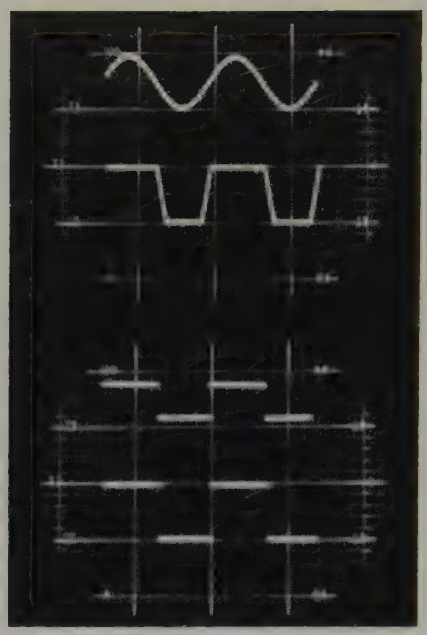


Fig. 9—(a) Signal voltage. Circuit: Fig. 6. Scale: 5 volts. Load: 10,000 ohms. Signal chopped: 5 volts d-c. (b) Signal voltage. Circuit: Fig. 6. Scale: 5 volts. Load: 10,000 ohms.

sistors are combined to form a *spdt* chopper used in this case in a balanced transformer input scheme. The *spdt* choppers with matched transistors and complete with isolating drive transformer are commercially available in a miniature seven pin base can (Airpax Electronics Incorporated, types 6025 and 6035). Modulation and demodulation of input and output for an operational amplifier is shown in *Fig. 12*. Clearly the transistor chopper can also be used in a host of other circuit applications where mechanical choppers are now employed.*

*Cook, H. A., "The Contact Modulator, Part IV," Airpax Electronics, Incorporated, Ft. Lauderdale, Fla.

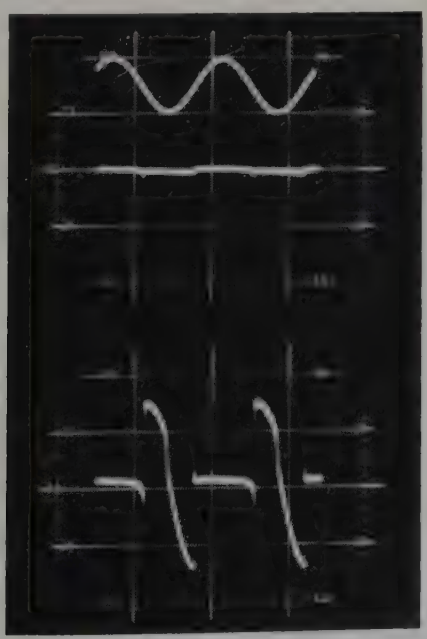


Fig. 10—(a) Noise voltage. Circuit: Fig. 4. Scale: 2 *mv*. Load: 100 ohms. (b) Noise voltage. Circuit: Fig. 4. Scale: 20 *mv*. Load: 10,000 ohms.

The question naturally occurs, will the transistor entirely replace the contact modulator? The answer at the moment is no, for the reason that in most applications such as *dc* amplification, choppers are used because of their low noise level. Here the transistor

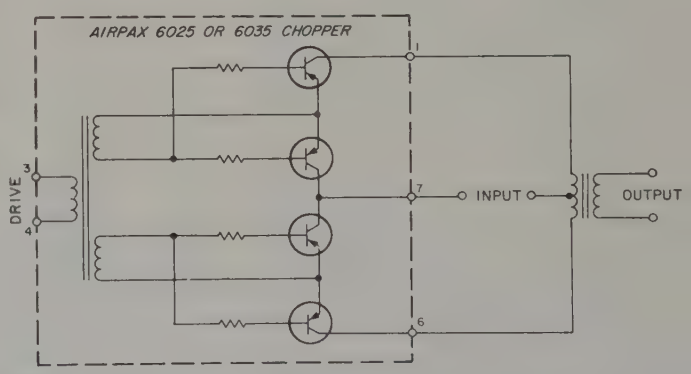


Fig. 11—Bilateral *spdt* transistor chopper used as a full wave modulator.

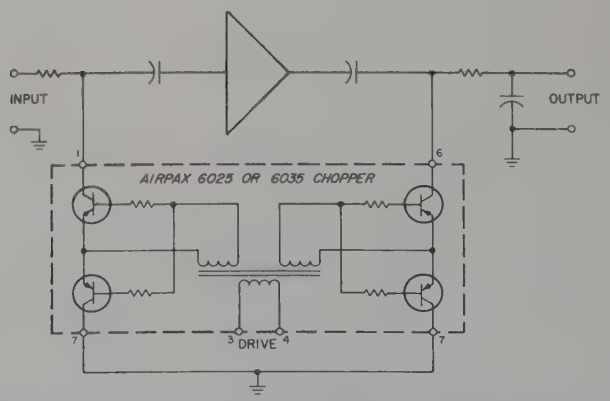


Fig. 12—Bilateral *spdt* transistor chopper used as an input modulator-output demodulator.

chopper cannot compete. It is difficult to pin this down quantitatively since, as has been shown, noise or offset depends quite markedly on the circuitry immediately surrounding the chopper. However, in the case of a carefully designed *dc* chopper amplifier the offset and drift referred to the input over ambient changes can be held to within 1 or 2 microvolts with the contact modulator, while with the transistor chopper this figure would be about 50 or 100 microvolts.

Life of transistor choppers is not yet known. Theoretically, the life of transistors is indefinite when conservatively used but on the other hand, the electro-mechanical chopper is much less susceptible to catastrophic overloads than is the transistor. Life of electro-mechanical choppers is presently in the 2,000 to 5,000 hour range.

APPLICATIONS ENGINEERING DIGESTS

APPLICATIONS ENGINEERING DIGEST NO. 57

(Circle 198 on Reader Service Card)

Silicon Transistor Low Noise Audio Frequency Amplifiers; Texas Instruments Incorporated, Dallas, Texas.

This Application Digest describes a low-noise, audio-frequency amplifier design using silicon transistors. This is done by first presenting transistor noise data and then showing the use of this data to design an amplifier with predictable noise performance. The 2N338 is used; its high gain at low current levels together with its low leakage currents make it suitable for amplifier input stages. The noise performance data is shown for a temperature range of −52 to +100°C, enabling the design of low-noise input stages using the 2N338 over this temperature range.

Types of noise

Noise can be defined as any unwanted signal present in the amplifier. This digest will consider only those unwanted signals which are generated within the transistor. In classifying these noises three types are usually distinguished: thermal, shot, and excess or $1/f$ noise. Thermal noise is caused by the random motion of carriers in the transistor's bulk resistance. Shot noise can be attributed to random diffusion of minority carriers and to random recombination and generation of hole-electron pairs. This type of noise is independent of frequency to a value of approximately $(1 + h_{fb})^{1/2} \times f_\alpha$. $1/f$ noise can be attributed to fluctuations in the current density caused by some modulation mechanism. Generally $1/f$ noise is divided into a component caused by random changes at the transistor's surface and a component caused by random variations in the leakage path around the transistor's junctions (primarily the reverse-biased collector junction). The main characteristic of $1/f$ noise is its $1/f^n$ spectrum.

Design of Low Noise Amplifiers

To demonstrate how the presented noise data can be used in design, the test amplifier in *Fig. 57.1* was designed. The amplifier was driven with an $R_G = 5.6$K ohms. A first-stage noise figure of 5 *db* ($f = 1.41$ *kc*) can be achieved if the transistor is biased at $I_E = 20$ μa and $V_{CE} = 5$ volts. The resistor values chosen for the bias network are determined by bias stability factors.

$$S_1 = \frac{\delta I_C}{\delta I_{CBO}} = \frac{R_B + R_E}{R_B\,(1 + h^*_{FB}) + R_E}$$

$$S_2 = \frac{\delta I_C}{\delta V_{BE}} = \frac{h^*_{FB}}{R_B\,(1 + h^*_{FB}) + R_E}$$

$$S_3 = \frac{\delta I_C}{\delta h^*_{FB}} = S_1\, I_{Eq}$$

where:

R_B = Thevenin's equivalent resistance of base bias supply, and

R_E = external *d-c* emitter resistance.

The total collector current change is equal to the sum of the individual changes. The effect of the base divider network and any un-bypassed emitter resistance will always increase the minimum transistor noise factor for a given bias condition, $F_{(min)}$, and will increase or decrease the value of R_G required to give this minimum, $R_{G(opt)}$. If the following conditions are satisfied however, this effect will be negligible:

1. $R_B/R_G > 10$
2. $R_e/R_G < 0.1$ (R_e is the un-bypassed emitter resistance)

The second stage is operated at $I_E = 100$ μa and $V_{CE} = 5$ volts. The generator resistance seen by this stage is equal to the parallel combination of the base-bias network and *d-c* collector load resistance of the first stage. This results in $R_G = 100$K ohms for the second stage, and gives an approximate $F = 12.34$ *db*. Since

$$F_A = F_1 + \frac{F_2 - 1}{G_1}$$

$$F_A = F_1$$

$$\text{if } \frac{F_2 - 1}{G_1} \ll F_1$$

In this application: $\dfrac{F_2 - 1}{G_1} = 0.1\, F_1$

This was considered a great enough difference for the noise of the second

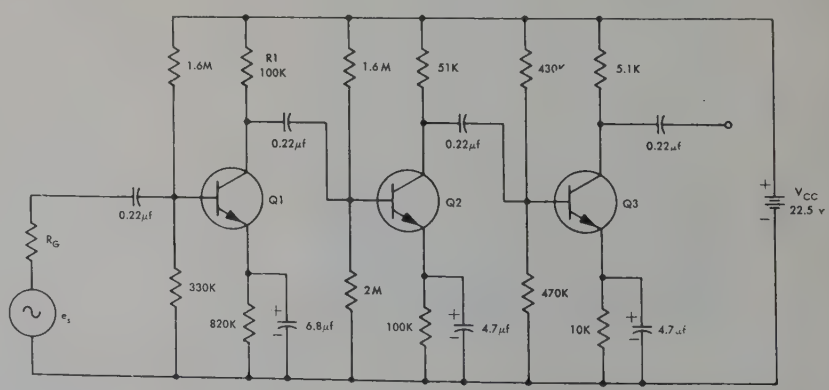


Fig. 57.1—Low noise test amplifier.

stage to be neglected. The gain of the first stage necessary to satisfy this condition is $G_1 = \frac{F_2 - 1}{0.1\,F_1}$

Inserting the known values of F_1 and F_2 gives:

$$G_1 = \frac{17.2 - 1}{0.1\,(3.16)} = \frac{16.2}{0.316} = 51.3 = 17.1\ db$$

The first-stage gain requirement can be reduced if the generator resistance seen by the second stage is nearer optimum. The obvious method is to use transformer coupling. If *RC* coupling is used, a small *d-c* voltage drop across R_1 will help. Another method is to bypass part of R_1 to ground.

The remaining amplifier design is straightforward unless some type of feedback is employed for *a-c* stability. The effect of feedback on the noise factor and its optimization depends on the particular application. This topic is covered in various references.

Amplifier Performance

Noise performance of the test amplifier is shown in *Fig. 57.2* and *57.3*. *Fig. 57.2* is a plot of F_A versus frequency, while *Fig. 57.3* shows the variation of F_A with generator resistance. The noise figure of the amplifier was measured at $f = 1.41$ *kc* and $T_A = 100°C$. Measurements were made using two different transistors in the first stage. The noise figures were 5 *db* and 5.2 *db* respectively. Measurements were also made at $T_A = -50°C$. The measured noise figures were 20 *db* and 15 *db*. It is obvious that the conditions necessary for $F_A \approx F_1$ do not hold at this temperature. This condition is due primarily to the increase in F_2 and the decrease of G_1 at $T_A = -50°C$.

Transformer coupling between the first and second stage would substantially improve amplifier performance for low temperatures. This is primarily due to the lower values of F_2 obtained by optimizing the generator resistance seen by the second stage. Several points must be kept in mind while evaluating the variation of noise factor with temperature. The data is based on only three units; there is no justification for saying all 2N338's will have the same characteristics; and surface conditions play a major part in 1/*f* noise, which explains the many variables associated with this type of noise.

The compromises necessary for low-noise performance are due to the low levels of emitter current required, which reduces the magnitude of both h_{fb} and f_α. However, these reductions do not place a serious handicap on 2N338 performance. For example, the voltage amplification of the amplifier was 2000 ($v_{out} = 1$-volt *rms*) at $T_A = -50°C$ and the 3-*db* bandwidth was 80 *cps* to 30 *kc*. If operation over a wider frequency range is required, then the primary compromise will be between bandwidth and noise performance.

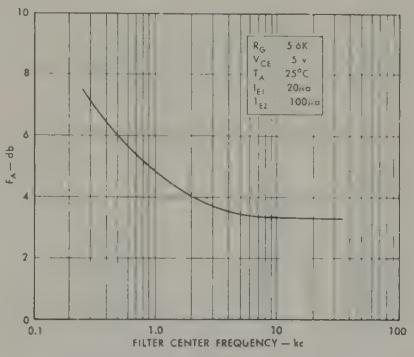


Fig. 57.2—F_A *vs.* F—test amplifier

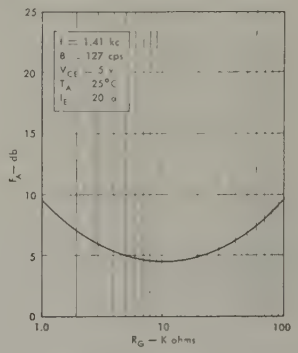
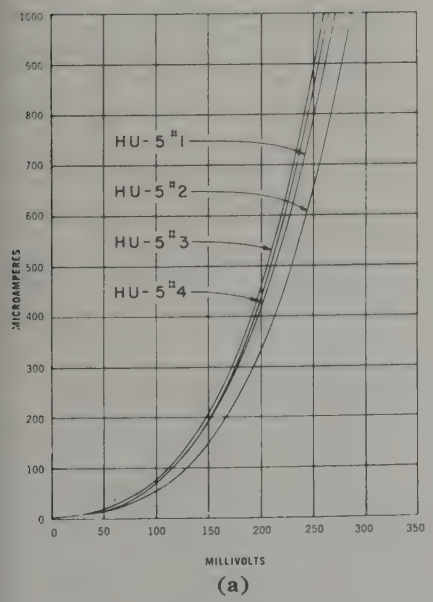


Fig. 57.3—F_A *vs.* R_g test amplifier

APPLICATIONS ENGINEERING DIGEST NO. 58

(Circle 199 on Reader Service Card)



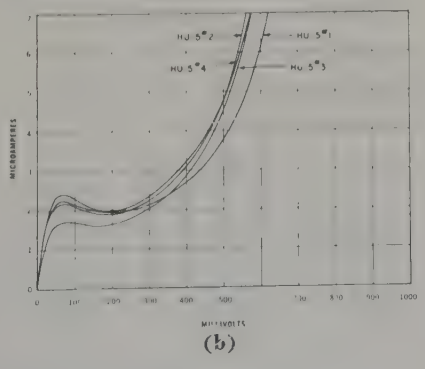


Fig. 58.1—(a) Uni-tunnel type HU-57 forward characteristics. (b) Uni-tunnel, type HU-5, reverse characteristics.

Silicon Uni-Tunnel Diodes for Low Level Bridge Modulation; Hoffman Electronics Corp., El Monte, Calif.

The Hoffman Silicon uni-tunnel diode, or "backward" diode, is a unique development of tunnel diode technology which utilizes the quantum mechanical tunneling effect to produce high forward conductance at low voltage levels (*Fig. 58.1a*). When biased in the reverse direction, the uni-tunnel diode exhibits a leakage tunneling current of microampere magnitude, as shown in *Fig. 58.1b*. The device is highly stable over an operating temperature range of −85°C to +200°C. When used as a rectifier, the uni-tunnel diode has a forward voltage drop many times smaller than that of a conventional diode while maintaining high reverse impedance.

The characteristics of the uni-tunnel diode, previously unattainable in semiconductor devices, make it ideal for application in modulators, computers, detectors, clampers, and tunnel diode circuitry. This digest will present the use of the uni-tunnel diode in one such application: low-level bridge modulation.

General Description

The bridge modulator circuit shown in *Fig. 58.2a* utilizes four Hoffman-type HU-5 silicon uni-tunnel diodes. The circuit may best be understood by com-

paring it to the mechanical shunt switch shown in *Fig. 58.2b* which is an exact equivalent if the carrier is an *a-c* square wave.

When the shunt switch is in its "on" state, the output is zero (short circuited), and when the switch is in its "off" state, the signal appears in the output. Similarly, when the four unitunnel diodes in the bridge modulator circuit are forward biased, assuming all four are equal, the output is essentially short circuited. When reverse biased, an open circuit is obtained and the input signal appears at the output.

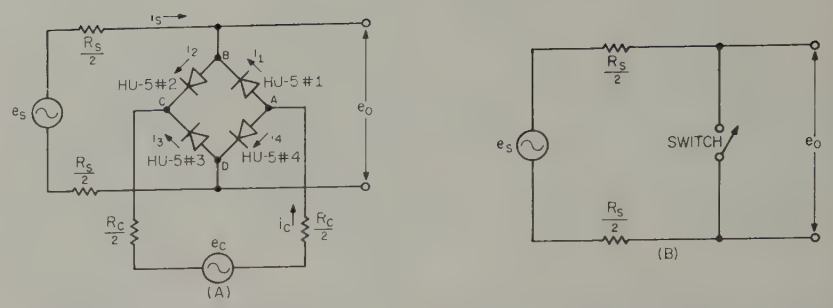


Fig. 58.2—(a) Modulator circuit (theoretical). (b) Equivalent shunt switch.

APPLICATIONS ENGINEERING DIGEST NO. 59

(Circle 200 on Reader Service Card)

10 mc Schmitt Trigger; Motorola Semiconductor Products Inc., Phoenix, Arizona. (W. D. Roehr)

Basic Circuit

The operation of this circuit is easily explained, using the basic circuit shown in *Fig. 59.1*. The *d-c* conditions are adjusted so that T_1 is conducting heavily and T_2 is cut off. A workable set of voltages are shown on the figure. A positive going input signal starts to cut off T_1, causing its collector voltage to rise toward V_{cc}, turning on T_2. The resulting increase in current through the common emitter resistor produces a voltage which serves to speed the cut off of T_1. Return to the original state occurs when the input signal again allows T_1 to conduct. The circuit must obviously be unsymmetrical, because the *on* current through T_2 must be greater than the *on* current of T_1 in order to hold T_1 cut off. The greater the loop gain of the system, the better will be the "snap" action of the circuit. That is, the region of input voltage where erratic operation occurs will be minimized. Therefore, a "speed-up" capacitor C_2 is generally needed to increase loop gain during the switching interval. The circuit could also be used by having T_1 normally cut off and T_2 normally conducting.

A Practical Example

The basic circuit of *Fig. 59.1* was modified to produce a Schmitt Trigger which would operate from 100 *cps* to 10 *mcs*, using mesa type 2N695 and 2N705 transistors. The final circuit is shown in *Fig. 59.3*.

The basic limitation of the circuit speed is the "speed-up" network. The capacitor should be large for fast rise times, but the time constant must be small compared to the repetition frequency. Therefore, the emitter follower T_3 is employed to permit reduction of the values of resistors R_4 and R_5. The emitter follower also provides a low capacitance load on the collector of T_1. The second emitter follower T_4 provides a low impedance output.

Output waveforms at various frequencies are shown in *Fig. 59.2*. A 0.5 volt peak to peak input signal will produce a stable pulse output. The input impedance is 450 ohms at low frequencies, decreasing to approximately 400 ohms at 1 *mc* and 300 ohms at 10 *mc*. The output impedance is 30 ohms.

Performance at high temperatures was not checked, but 70 μa of I_{co} was simulated, using a battery and series resistor. D.C. potentials changed only slightly and changes in circuit operation were negligible. This value of I_{co} is typically what might be expected of the 2N695/2N705 at 100°C junction temperature. Excellent stability should be expected since the resistors used in the base circuits are small and the emitter resistors large, comparatively speaking. Random samples of 2N695 and 2N705 transistors have been used with no change in performance.

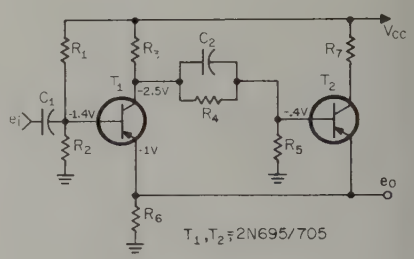


Fig. 59.1—Basic trigger circuit.

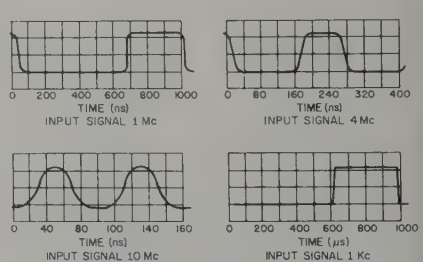


Fig. 59.2—Output waveforms.

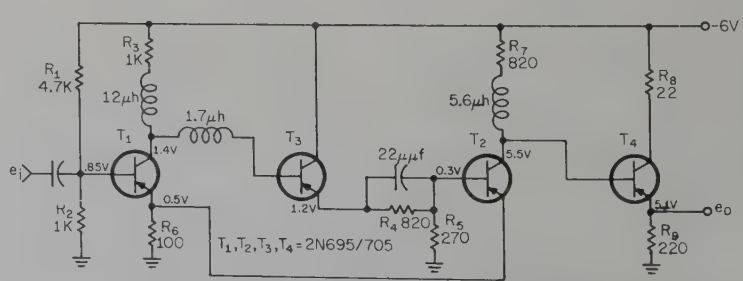


Fig. 59.3—The Schmitt trigger circuit.

PATENT REVIEW*

Of Semiconductor Devices, Fabrication Techniques and Processes, and Circuits and Applications

Compiled by SIDNEY MARSHALL

The abstracts appearing in this issue cover the inventions relevant to semiconductors from Oct. 21, 1958 to Nov. 25, 1958. In subsequent issues, patents issued from Nov. 25, 1958 to date will be presented in a similar manner. After bringing these abstracts up to date, PATENT REVIEW will appear periodically, the treatment given to each item being more detailed.

October 21, 1958

2,857,518 Transistor Blocking Oscillator—R. C. Reed. Assignee: North American Aviation, Inc. A blocking oscillator capable of high frequency operation and which maintains pulse width output under conditions of varying frequency input.

2,857,526 Selective Pulse Translating System—E. B. Galton. Assignee: Hazeltine Research Inc. A system which automatically compensates for alterations of transistor parameters.

2,857,527 Semiconductor Devices Including Biased P+P or N+N Rectifying Barriers—J. I. Pankove. Assignee: Radio Corporation of America. A device which reduces surface recombination velocity by employing a rectifying barrier between the surface region and the bulk of the body of the device, and by maintaining a difference of potential between the two regions sufficient to repel minority charge carriers.

2,857,560 Semiconductor Unit and Method of Making It—G. L. Schnable, M. Sadowsky. Assignee: Philco Corporation. A method of plastic encapsulation of a semiconductor device in a plastic material in which are embedded filler particles which promote the thermal conductivity of the casing.

2,857,573 Frequency Modulated Transistor Oscillator—H. C. Lin. Assignee: Radio Corporation of America. A transistorized frequency modulated carrier wave generator in which one transistor performs the function of a reactance tube, an oscillator, and a limiter.

October 28, 1958

2,858,199 Crystal Production—C. C. Larson. Assignee: International Telephone and Telegraph Corp. A method in which a crystal of semiconductor is drawn in vacuum from a block of said substance, the central portion of which has been melted by electron bombardment.

2,858,239 Method for Producing Selenium Rectifiers—E. Nitsche. Assignee: Siemens Schuckertwerke Aktiengesellschaft. Method of manufacturing selenium rectifiers having low differential resistance with respect to their passage properties but which will sustain high blocking voltages.

2,858,246 Silicon Single Crystal Conductor Devices—G. L. Pearson. Assignee: Bell Telephone Laboratories. A device having a large number of minute discrete surface regions in a uniform geometrical configuration, the conductivity of said surface regions being opposite to that of the base material.

2,858,371 Telephone Subscribers Apparatus—A. F. Jones. Assignee: General Electric Co. Ltd. A telephone set which includes a transistor amplifier.

2,858,379 High Input Impedance Transistor Amplifier Circuits—T. O. Stanley. Assignee: Radio Corporation of America. An amplifier circuit with high input impedance in which output load impedance variations have a negligible effect on the input impedance.

2,858,423 Feedback Circuit for Semiconductor Amplifiers—A. P. Stern. Assignee: General Electric Company. An automatic gain control circuit for a semiconductor amplifier.

2,858,424 Transistor Amplifier with Automatic Collector Bias Means Responsive to Signal Level for Gain Control-A. P. Stern, J. A. Raper, Assignee: General Electric Company. A circuit, the amplitude stabilizing properties of which are independent of fluctuations in supply voltage.

2,858,438 Voltage Comparators—L. C. Merrill. Assignee: International Telephone & Telegraph Corporation. A multiar-type circuit for comparing two voltages and for obtaining a distinct signal when those two voltages are equal.

2,858,456 Power Control Circuitry—G. H. Rayer, R. L. Bright. Assignee: Westinghouse Electric Corporation. A pulse width modulator for a power control circuit, the output voltage of said modulator having a time duration that is functionally related to the amplitude of the direct control voltage.

2,858,489 Power Transistor—H. W. Henkels. Assignee: Westinghouse Electric Corporation. A high power junction transistor having small current flow paths between the emitter and the base, and broad area metal surface electrode structures to which heat exchange surface may be connected.

November 4, 1958

2,858,598 Manufacture of Crystal Contact Devices—R. G. Power, C. Green, G. Mayes. Assignee: The General Electric Company Ltd. A contact assembly for crystal contact devices, wherein the spacing between the various contact points are accurately fixed.

2,858,730 Germanium Crystallographic Orientation. J. S. Hanson. Assignee: International Business Machines Corporation. An optical method of orienting a monocrystalline germanium ingot to determine the location of a particular crystallographic plane and a means for mounting said ingot for dicing normal to a particular axis of the crystal structure.

2,859,140 Method of Introducing Impurities Into A Semiconductor—E. N. Clark. Assignee: Sylvania Electric Products. A controlled heating and fusion method.

2,859,141 Method for Making a Semiconductor Junction—S. P. Wolsky. Assignee: Raytheon Manufacturing Company. A device having a fusion type junction which is created by rapid cooling and recrystallization of a quanity of molten indium on a germanum base.

2,859,142 Method of Manufacturng Semiconductor Devices—W. G. Pfann. Assignee: Bell Telephone Laboratories. A method involving wetting two electrodes with molten semiconductive material, said electrodes being spaced so that surface tension causes a continuous portion of molten semiconductor between them.

2,859,286 Variable Gain Devices—D. P. Kennedy. Assignee: Raytheon Manufacturing Company. A transistorized automatic gain control system.

2,859,289 Transistor Controlled Magnetic Amplifier—C. B. House. Assignee: None. A transistor controlled, half-cycle response time, magnetic amplifier, including a compensating circuit for transistor characteristics.

2,859,356 Transistor Control Circuit for Parallel Generators—C. W. King. Assignee: General Motors Corporation. Means of controlling the field of two variable speed alternators connected in parallel so that their outputs will be equal.

2,859,357 Control Circuit For Parallel Generators—W. H. Schmeling. Assignee: General Motors Corporation. Means of controlling the field of two *d-c* generators connected in parallel so that their outputs will be equal.

2,859,360 Wave Generator—J. J. Suran. Assignee: General Electric Company. A method for obtaining constant charging current in a semiconductor saw-tooth wave generator circuit.

2,859,393 Electric Semiconductor Devices—J. N. Aldington. Assignee: Siemens Edison-Swan Ltd. (England). A semiconductor device wherein the crystal is in the form of a lamina with electrodes bearing against opposite sides thereof.

*Source: Official Gazette of the U. S. Patent Office and Specifications and Drawings of Patents Issued by the U. S. Patent Office.

2,859,394 Fabrication of Semiconductor Devices—J. Berman. Assignee: Sylvania Electric Products. A method of manufacturing a point-contact device wherein the semiconductor element is brazed onto its support.

2,859,407 Method and Device for Measuring Semiconductor Parameters—H. K. Heinsch. Assignee: Sylvania Electric Products Inc. A method of using an electrically energized coil and a source of radiation to measure the resistivity and minority carrier lifetime of a semiconductor specimen.

2,859,408 Binary Pulse Modulator—J. Holzer. Assignee: U.S.A. (Department of the Army). A modulation system in which every *d-c* level provides a discrete code output and in which errors due to incorrect interpretation at an intended receiver are not cumulative.

November 11, 1958

2,860,193 Stabilized Transistor Amplifier—J. E. Lindsay. Assignee: Radio Corporation of America. In a class B amplifier, circuitry providing a large degree of *d-c* stabilization with every little *a-c* degeneration.

2,860,195 Semiconductor Amplifier Circuit—T. O. Stanley. Assignee: Radio Corporation of America. A push-pull amplifier circuit with a transistor driving stage, said circuit providing efficient coupling of the driver signal current to the push-pull stage.

2,860,196 Transistor Amplifier With Overload Protection—J. B. Schultz. Assignee: Radio Corporation of America. A circuit for preventing the overloading of the signal amplifying stage of a radio receiver and for allowing satisfactory operation without appreciable distortion despite the reception of very strong signals.

2,860,218 Germanium Current Controlling Devices—W. C. Dunlap Jr. Assignee: General Electric Company. Germanium devices which are highly thermoconductive and photoconductive when maintained at temperatures between —100°C to —200°C.

2,860,219 Silicon Current Controlling Devices—E. A. Taft, Jr., F. H. Horn. Assignee: General Electric Company. Silicon devices having highly thermosensitive resistivities in the range —80°C to 100°C, and having pronounced photoconductive properties, particularly in the infrared range at temperatures between —100°C to —200°C.

2,860,215 Apparatus for Manufacturing Semiconductor Devices—S. Pakswer, R. G. Pohl. Assignee: The Rauland Corporation. Apparatus for forming alloy-type junctions upon a selected limited area of the surface of a semiconductor after having precisely determined the location of said junction.

2,860,258 Transistor Decade Counter—A. D. Hall. Assignee: Bell Telephone Laboratories. A decade counter in which four single transistor trigger stages are connected in tandem and in which circuitry is used to make the counter reset at the tenth pulse.

2,860,259 Electrical Circuits Employing Transistors—A. D. Odell, J. D. Reynolds, P. W. Harrild. Assignee: International Standard Electric Corporation. A multistable register circuit including a single crystal triode for each stage thereof.

2,860,260 Transistor Integrator—L. Sykes. Assignee: USA (Department of the Navy). A transistorized, direct noninverted voltage output producing voltage integrator which uses silicon high-alpha junction transistors.

2,860,261 Device for Supplying a Signal to One of a Plurality of Output Conductors—A. F. Verkruissen. Assignee: North American Philips Company, Inc. The circuit achieves its objective by means of chain of voltage controlled change-over contacts.

2,860,291 Junction Type Transistor Structure—E. C. Karnavas. Assignee: Texas Instruments Inc. In an *n-p-n* junction transistor a crystal contact wire is fused to the *p* layer in such a way as to penetrate the crystal during the operation.

2,860,322 Barium Titanate Memory Device—H. L. Stadler. Assignee: Bell Telephone Laboratories. A method of eliminating decay of the polarization of a barium titanate crystal under repeated pulsing by cooling and maintaining the crystal to below —195°C.

November 18, 1958

2,861,017 Method of Preparing Semiconductor Devices—V. W. Bearinger. Assignee: Minneapolis Honeywell Regulator Company. A method of forming a junction which reduces the tendency of the junction forming materials to migrate into the semiconductor body.

2,861,018 Fabrication of Semiconductor Devices—C. S. Fuller, M. Tannenbaum. Assignee: Bell Telephone Laboratories. A diffusion method for controlling the configuration and location of *p-n* junctions in silicon junction transistors.

2,861,160 Making Photodetectors—S. H. Hersh. Assignee: None. Application of a direct voltage across the mating surfaces of a pair of cadmium sulphide crystals renders them photoconductive.

2,861,161 Photoconductive Target—N. C. Anderson. Assignee: Electronics Corporation of America. A plate shaped target on which is an array of layer type photoconductive areas.

2,861,165 Infrared Emitting Devices—P. Aigrain, C. Benoit. Assignee: Compagnie Generale Telegraphie Sans Fils (France). A semiconducting body provides controllable infrared emitting device having small volume and requiring low modulating energy.

2,861,199 Latch Circuits—R. A. Henle. Assignee: International Business Machines Corporation. A bistable single transistor latch circuit utilizing a high current-gain transistor.

2,861,200 Trigger Circuits Employing Junction Transistors—R. A. Henle, R. W. Emery, G. D. Bruce, O. L. MacSorley. Assignee: International Business Machines Corporation. A transistorized trigger circuit operable at high signal pulse frequencies.

2,861,201 Electronic Pulse Scaling Circuits—E. H. Cooke. Assignee: USA (Atomic Energy Commission). A scaling circuit employing a common turn-off pulse and employing fewer elements than the scaling factor of the circuit.

2,861,226 High Current Rectifier—W. F. Lootens. Assignee: General Electric Company. A semiconductor junction rectifier capable of passing 50 amperes at 300 volts peak inverse voltage and capable of withstanding a corresponding 50 watt heat dissipation.

2,861,227 High Voltage Dry Rectifier—F. Scherbaum. Assignee: Siemens-Schuckertwerke Aktiengesellschaft (Germany). A multistack annular shaped space saving dry rectifier.

2,861,228 Semiconductor Unit—G. C. Rich. Assignee: Motorola Incorporated. A point contact transistor having emitter and collector electrodes which are thin metallic coatings on an insulating disc and which are in substantially point-contact with the interface junction of a semiconductive crystal.

2,861,229 Semiconductor Devices and Methods of Making Same—J. I. Pankove. Assignee: Radio Corporation of America. A photoconductive device employing a germanium body having a hook-type electrode.

2,861,230 Calorized Point Contact Electrode for Semiconductor Devices—T. E. LeLoup. Assignee: General Electric Company. A point-contact device wherein the described platinum point-contact electrode is calorized by heating in a mixture of aluminum and alumina powders and thereafter subjected to a nonoxidizing heat treatment.

2,861,237 Transistor Switch Voltage Regulator—W. B. Zelina. Assignee: General Electric Company. A voltage regulator for a generator which uses a transistorized rectangular wave oscillator the output voltage of which has no significant average *d-c* component.

2,861,258 Transistor Amplifier Circuit—J. C. Logue, R. L. Martin. Assignee: International Business Machines Corporation. A high input impedance, wide bandwidth, transistor amplifier circuit including a two-transistor single-shot trigger circuit; used for generating a square wave output in response to signal pulses from a magnetic read head.

November 25, 1958

2,861,903 Method of Forming Photoresistive Coatings and Composition—W. Heimann. Assignee: Societe Nouvelle de L'Outillage R.B.V. et de La Radio Industrie (R.B. VR.I) (France). An infrared sensitive photoresistive material made of cadmium sulphide and a selenium or tellurium compound additive, said material being capable of a few milliwatt power output without the use of an amplifier.

2,861,909 Semiconductor Devices—S. G. Ellis Assignee: Radio Corporation of America. A method for making large area efficient current collecting electrodes for semiconductor devices.

2,861,931 Electrolytic Etching Process—J. W. Faust Jr. Assignee: Westinghouse Electric Corporation. A method for electrolytically etching silicon in which an electrolyte consisting of hydrofluoric acid and an anhydrous hydrophillic solvent is employed.

[To Be Continued]

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TITLE	PUBLICATION	CONDENSED SUMMARY	AUTHORS
Contact Electrification of Semiconductors	Br JL Appd Phys Aug 1960	Recently published experimental finding on the electrification of rutile powder by sliding down a metal chute can be explained by an extension of the present author's theory of the separation electrification of metals.	W. R. Harper
Transistor Dissipation During Fast Switching	Control Engg Aug 1960	Equations account for the dissipations during three different types of rise and fall curves encountered in commonly used transistor circuit.	E. J. Currence J. A. Wheeler
Function Generators Using the Hall Effect	Elecl Mfg Aug 1960	Theory and backgrounds of Hall Effect principles as applied to rotary instruments and devices.	L. J. Brady B. A. Melchy
Designing Passive and Tunnel-Diode Network—1	Elecl Mfg Aug 1960	Modern synthesis techniques for realizing prescribed frequency characteristics by dissipative networks and by amplifier networks containing tunnel diodes.	L. Weinberg
Silicon Transistor-Resistor Logic Circuit	Elecl Mfg Aug 1960	Principles, circuit design, and switching times of transistor-resistor logic are discussed.	J. Luecke
Design of a Long Time Constant Asymmetrical Transistor Multivibrator	Elecnc Design Aug 3, 1960	The design steps together with a special Equation Derivation section are presented as an aid in such applications.	M. I. Marks
Designing Low Noise Transistor Circuits	Elecnc Design Aug 3, 1960	A brief description of noise sources and their origin, considerations in circuit design and a typical design example involving a low noise application is presented.	P. J. Beneteau
Wideband Video Amplifier Design Using Mesa Transistor	Elecnc Design Aug 17, 1960	Design details for a 150 *mc* video amplifier strip having an overall gain of 50.5 *db*.	W. A. Rheinfelder
Flow Graph Speeds Transistor Circuit Analysis	Elecnc Design Aug 31, 1960	Application of flow graphs enables the designer to easily keep track of resistive parameters, hybrid parameters, voltages and currents.	
Optimum Design of Transistor Communications Circuits	Elecl Des News Aug 1960	Brief notes on design techniques are given.	C. D. Simmons
Drive Circuit Design for High-Speed Memories	Elecnc Equip Engg Aug 1960	Basic memory unit with capacity of 114,688 bits is expandable to over 1.8 million bits	G. R. Gaschnig et al.
Controlled Rectifier Frequency Multiplier Uses Inverter Principles	Elecnc Equip Engg Aug 1960	Output frequency of the frequency changer is independent of the supply frequency because communication is obtained primarily from capacitors instead of the power line voltage.	C. W. Flairty J. D. Harnden, Jr.
The Binistor A New Semiconductor Device	Elecnc Industries Aug 1960	Description and application of a new semiconductor device —the binistor developed for switching and storage circuits.	N. De Wolf
Determining Transistor Power Dissipation	Elecnc Industries Aug 1960	Maximum power will be dissipated at the collector when the load voltage (in a CE circuit) equals the collector to emitter voltage. This permits determining the minimum load resistance for a given power supply voltage.	J. G. Naborowski
Turn-Off Circuits for Silicon Controlled Rectifiers	Electronics Aug 5 1960	Triggering and turn-off circuits for controlling rectifiers are described with particular emphasis on inverter applications.	D. V. Jones
Tracing Tunnel Diode Curves	Electronics Aug 5 1960	Diode holder uses germanium blocks for low inductance resistors; allows a curve tracer that will show the characteristic curves of most tunnel diodes.	H. G. Diel M. R. MacPherson
Transistor Heat Sink Calculations	Electronics Aug 5 1960	Calculations are simplified if radiation cooling alone is considered; the problem is then solved by using a flat plate as the heat sink for all transistors.	M. Greenbaum
Analog Multiplication Using Time as One Variable	Electronics Aug 8 1960	Electronic multiplication can be implemented simply and accurately if one or more of the variables inherently appear as a time variable.	T. R. Hoffman
Circuit Applications of Field Effect Transistors	Electronics Aug 8 1960	Characteristics of cadmium-sulfide transistor are compared with those of junction transistor, vacuum triode and vacuum pentode.	R. R. Bockemuehl
Combining Transistors with Tunnel Diodes	Electronics Aug 19 1960	Bistable memory elements and circuits with *n*-type characteristics can be obtained with transistor, tunnel diode combinations.	C. D. Todd
Simplified Curve Tracer for Transistors and Diodes	Electronics Aug 19 1960	Staircase waveform generator supplies test transistor with six values of base current during each cycle to develop family of curves.	J. C. Candy
Transistor Operation Beyond Cutoff Frequency	Electronics Aug 26 1960	Special converter circuits allows useful amplification considerably beyond the normal frequency.	V. W. Vodicka R. Zuleeg
Semiconductor Clamp Handles Millivolt Signal	Electronics Aug 26 1960	Usual potential difficulties associated with semiconductor components are overcome by a bridge configuration.	A. J. Kael E. Bleckner O. C. Srygley
Transistors in Audio and Carrier Frequency Amplifiers	Elecnc Tech Aug 1960	This paper discusses the characteristics of common emitter transistor amplifiers in relation to the specific requirements of communication systems.	K. Lamont
Controlled Semiconductor Rectifier	Elec Tech USSR July 1960	Discussion of possibility of making a controlled semiconductor rectifier whose controlling element is a semiconductor triode.	E. Ia. Pumper
Statistical Analysis of Transistor-Resistor Logic Networks	IRE Tr Circ Theory Spec Supplement Aug 1960	A general approach to statistical investigation of properties of complex transistor switching networks.	W. J. Dunnet Yu-Chi Ho
Application of Synthesis Techniques to Electronic Circuit Design	IRE Tr Circ Theory Spec Supplement Aug 1960	Four very useful RC-active network synthesis techniques developed during the past decade are reviewed and compared from the points of view of generality and sensitivity.	F. H. Blecher
Switching and Memory Criterion in Transistor Flip-Flops	IRE Tr Circ Theory Spec Supplement Aug 1960	A simple criterion is proposed to determine which storage elements can provide memory.	D. K. Lynn D. O. Pederson
A Transistorized Receiver for 150 MC Mobile Service	IRE Tr Vehic Comm Aug 1960	Block diagram and circuit diagram analysis. Receiver operates on 40 ma or less from a 13.8 volt battery.	R. T. Myers

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A Tunnel Diode Crystal Calibrator	JL Br Inst RE Aug 1960	Description of calibrator which has relatively flat output in the *h-f* band. Operates at 100 *kc* or 1000 *kc* and their harmonics.	L. G. Cox
Transistor Beta-Phase-Shift Oscillator	JL Elecncs Cont (Br) Aug 1960	Makes use of the internal phase-shift of a transistor and employs a single C-R section of the external phase-shifting network.	A. R. Saha
Electroluminescent Phosphors	Jl Electrochem Soc Aug 1960	With solid solutions of (Zn, Hg)S and suitable additions of Cu and a coactivator, photoluminescence is obtained.	A. Wachtel
The Analysis of Spectral Yield and Accelerating Field Characteristics of the Photoelectric Emission from Semiconductors	Jl Phys Chem Solids (Br) Aug 1960	The relation between yield and accelerating field characteristics of the photoelectric emission from semiconductors is discussed.	D. Haneman E. W. J. Mitchell
The Diffusion of Oxygen in Silicon and Germanium	Jl Phys Chem Solids (Br) Aug 1960	The diffusion coefficient of oxygen was calculated from experimental data on internal friction.	C. Hass
Diffusion of Zinc in Gallium Arsenide	Jl Phys Chem Solids (Br) Aug 1960	The diffusion of zinc into gallium arsenide from the vapor phase has been investigated for a range of diffusion temperatures and zinc pressures.	F. A. Cunnell C. H. Gooch
The Diffusion of Ionized Impurities in Semiconductors	Jl Phys Chem Solids (Br) Aug 1960	A simple model is used to illustrate that the diffusion coefficient of an impurity depends on the state of ionization of the impurity. This is then applied to the diffusion of ionized impurities in semiconductors.	J. W. Allen
Magneto-Plasma Resonance in Semiconductors	JL Phys Soc Japan Aug 1960	Theory of the magneto-plasma resonance in semiconductors is developed for the general case where several kinds of free carriers are moving under a static magnetic field.	M. Date
Photovoltaic Effect Produced in Silicon Solar Cells by X- and Gamma Rays	Jl Research Natl Bur Stds July/Aug 1960	The open circuit voltage and photo-current produced in a silicon solar cell by X- and gamma rays were measured as a function of exposure dose rate, cell temperature, angle of incidence of radiation, and photon energy.	K. Scharf
Production of Islands and Dice in Semiconductor Slices with an Ultrasonic Drill	JL Scient Insts (Br) Aug 1960	The production of islands of less than 0.002 in. in diameter is described; also tools and equipment used.	R. D. Knight
Ratiometer Phase Angle Indicator	JL Scient Insts (Br) Aug 1960	The principle of the moving coil ratiometer is described together with the circuit used with it for phase angle measurement.	K. L. Morphew
Transistor Operation of Electromechanical Registers	JL Scient Insts (Br) Aug 1960	A double-wound coil together with a transistor and rectifier are used in a blocking oscillator circuit for this purpose.	J. C. Barton
Power Amplifiers Based on Electro-Optical Effects; A Survey	Philips Res Repts Aug 1960	Special features arise from the change in nature of the power and from energy transport by quantum radiation.	G. Diemer J. G. Van Santen
Representations of Switching Functions and Their Applications to Computers	Philips Res Repts Aug 1960	Definitions, linear representation of switching functions, representation of B^n with the aid of logical sums, binary quantities applied to the description of the behavior of magnetic cores, application of the theory, etc.	H. J. Heijn
Spectral Distribution of the Photomagnetoelectric Effect in Ge: Experiment	Physical Review Aug 1 1960	The photo-electromagnetic effect has been studied in germanium as a function of the wavelength of incident radiation in the region from 0.5 to 2.0 microns.	F. A. Brand A. N. Baker H. Mette
Auger Electron Ejection from Germanium and Silicon by Noble Gas Ions	Physical Review Aug 1 1960	Experimental results concerning electron ejection from annealed, atomically clean surfaces of germanium and silicon by the singly charged ions of the noble gases are reported.	H. D. Hagstrum
Diffusion Rate of Li in Si at Low Temperatures	Physical Review Aug 15 1960	The method of ion drift in an electric field of an *n-p* junction has been used to measure the diffusion constant of Li in Si between 25°C and 125°C.	E. M. Pell
Charge Carrier Production and Mobility in Anthracene Crystals	Physical Review Aug 15 1960	The drift mobilities of electrons and holes in anthracene crystals have been measured using pulsed photoconductivity technique.	R. G. Kepler
Impurity Conduction in Transmutation Doped p-Type Germanium	Physical Review Aug 15 1960	The Hall coefficient and resistivity of germanium single crystals bombarded with slow neutrons were measured between 1.2 and 300° K.	H. Fritzsche
Transistorized Phase-Comparison Relaying: Principles and Circuits	Power App & Systems AIEE Aug 1960	Description of a new system of phase-comparison relaying for the protection of transmission lines.	C. G. Dewey M. E. Hodges
Transistorized Phase-Comparison Relaying: Applications and Tests	Power App & Systems AIEE Aug 1960	Discussion of field testing and application practices of a new system of phase-comparison relaying for the protection of transmission lines.	S. H. Horowitz A. J. McConnell H. T. Seeley
A Review of Panel-Type Display Devices	Proc IRE Aug 1960	A review of the activities of various governmental, industrial, and academic institutions is made in the field of panel display devices.	J. J. Josephs
Gallium Arsenide Tunnel Diodes	Proc IRE Aug 1960	The fabrication and properties of Ga as tunnel diodes are described.	N. Holonyak I. A. Lesk
Shot Noise in Tunnel Diode Amplifiers	Proc IRE Aug 1960	The contributions of Johnson noise and shot noise to the noise in a tunnel diode are analyzed according to a simple theoretical model.	J. J. Tiemann
A Parametric Device as a Nonreciprocal Element	Proc IRE Aug 1960	A parametric device has been proposed which is equivalent to a passive nonreciprocal phase shifter.	A. K. Kamal
On The Resolving Time And Flipping Time of Magnetoresistive Flip Flops	Proc IRE Aug 1960	The time constant of the exponential approach to the stable states is shown to be a fair approximation for the flipping time of the bridge magnetoresistance.	A. Aharoni E. H. Trei
Measurement of the Sheet Resistivity of a Square Wafer with a Square Four-Point Probe	Rev Scient Insts Aug 1960	Calculations have been made for the correction factors in the case of a square probe array placed symmetrically on a square wafer.	F. K. Keywell
A Transistorized High Speed Sequency Generator	Semiconductor Prods Aug 1960	An electronic circuit capable of generating multiple pulses in time sequential order is described.	C. D. Todd

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Thermistors In Transistor Circuits	Semiconductor Prods Aug 1960	Characteristics of available thermistors are discussed together with methods for determination of characteristics and a description of how they should be specified.	L. H. Hardy H. R. Emes
A Method For the Preparation of Semiconductor Grade Silicon	Semiconductor Prods Aug 1960	An apparatus for the thermal decomposition of silicon tetraiodide by film boiling on a graphite surface to produce semiconductor grade silicon at a rate of 120g per hour is described.	R. C. Ellis
Transistorized Equipment for Measuring Transistor Frequency Response	Semiconductor Prods Aug 1960	The theory and operation of a transistorized equipment capable of measuring the frequency response of transistors is described.	B. Reich W. Orloff
Thermal Expansion of Germanium at Low Temperatures	Sov Phys Solid State July 1960	Investigation reveals a negative region of thermal-expansion coefficient of germanium at temperatures less than 48°K.	S. I. Novikova
Non Equilibrium Carrier Lifetime in the Surface Layers of CdSe+Ag Monocrystals	Sov Phys Solid State July 1960	In the surface layer of an activated crystal the nonequilibrium carrier lifetime rises with a decrease in carrier generation depth.	U. B. Soltamov I. G. Perestoronin
Relation Between Excess Noise in Germanium And Surface Traps	Sov Phys Solid State July 1960	The McWharter excess-noise model for germanium fails to explain empirical results based on a test thereof.	D. N. Mirlin L. S. Sochava
Properties of *p-n* Junctions In Cadmium Telluride Photocells	Sov Phys Solid State July 1960	A description and discussion of empirical current-voltage characteristics of cadmium telluride photocells.	Y. A. Vodakov et al.
Thermally Stimulated Conductivity In Semiconductors	Sov Phys Solid State July 1960	A theory of thermally stimulated conductivity is constructed on the basis of a general model of a semiconductor.	I. I. Boiko E. I. Rashiba A. P. Trofimenko
The Role Of Impurity In The Conductivity Of Vitreous As_2SeTe_2	Sov Phys Solid State July 1960	An experimental investigation of the property changes resulting from transition of the system from the vitreous to the crystalline state.	B. T. Kolomiets T. F. Nazarova
Solid Solution In Quaternary Systems Formed From InAs and InSb	Sov Phys Solid State July 1960	A study of the formation of solid solutions in the system $mCdSnAs_2 - n(2InSb)$.	N. A. Goryunova V. D. Prochukhan
Spectral Distribution of the Internal Photoelectric Effect and the ZnSe-CdSe System	Sov Phys Solid State July 1960	A study is made of the change in the photoelectric properties of the ZnSe-CdSe system during a transition from a ZnSe to a CdSe structure.	B. T. Kolomiets C. Lin
Intrinsic Optical Absorption in Amorphous and Crystalline Germanium	Sov Phys Solid State July 1960	Investigation of amorphous and crystalline germanium in the region of strong absorbtion, and the study of close range and distant range order on the properties of semiconductors.	P. G. Borzyak R. D. Fedorovich
Volume Recombination in *p*-Type Silicon Subjected to Heat Treatment at High Temperatures	Sov Phys Solid State July 1960	Tests of the properties of recombination centers produced by heat treatment of *p*-type silicon at temperature above 1200°C produce results that agree with a simple Shockley-Read model with one recombination center.	G. N. Galkin
A *p-n* Junction Photocell Made of Cadmium Telluride	Sov Phys Solid State July 1960	The voltage-current characteristics, spectral sensitivity, and solar energy conversion efficiency of the photocell are discussed.	Y. A. Vodakov et al.
Some Optical Properties of Solid Solutions of Arsenoselenides and Arsenotellurides of Indium	Sov Phys Solid State July 1960	Experimental results support the possibility of obtaining materials with intermediate forbidden-zone width values between the ΔE values of the starting binary components of the systems investigated.	D. N. Nasledov M. P. Pronina S. I. Radautsan
Dispersion of Light In Germanium	Sov Phys Solid State July 1960	The dispersion of light in germanium is described by a formula containing only a single term with complete determination of the energy transition.	M. I. Kornfel'd
The Mechanism of Photo Conductivity in Amorphous Chalcogenides	Sov Phys Solid State July 1960	A study of the dependence of photocurrent on illumination at comparatively high temperatures in amorphous photoconductors.	B. T. Kolomiets V. M. Lyubin
Investigation of Surface Layers in Cadmium Telluride Crystals	Sov Phys Solid State July 1960	Relatively lengthy atmospheric exposure or high temperature heating initiate irreversible property changes at the surface of CdTe crystals.	Yu A. Kodakov et al.
The Voltage Sensitivity of Hall-EMF Probes	Sov Phys Solid State July 1960	In a discussion of Hall probe sensitivity it is pointed out that the sensitivity of an InSb probe at low temperatures (120°K) is 400 times greater than its sensitivity at room temperature.	V. V. Galavanov
Electrokinetic Effects in Liquid Semiconductors	Sov Phys Solid State July 1960	Electrokinetic effects in a liquid semiconductor are caused by the layer formed by the space charge at the surface.	V. B. Fiks G. E. Pikus
Determination of Impurity Concentration On Germanium	Sov Phys Solid State July 1960	A method of determining impurity concentration by considering the effect of the carrier scattering by impurities on the electrical resistivity at a given temperature.	R. M. Vinetskii E. G. Miselyuk
Secondary Electron Emission From Thin Metal Films On An Activated Base	Sov Phys Solid State July 1960	The rate of inelastically reflected electrons in secondary electron emission from a thin metal film is checked using activated metal film supports.	I. M. Bronshtein R. B. Segal
Theory Of Anisotropic Photomagnetic Effect in Germanium	Sov Phys Solid State July 1960	A theoretical discussion of the causes of the even photomagnetic effect.	A. A. Grinberg
The Absorption Of Light In Germanium	Sov Phys Solid State July 1960	A simple expression for the temperature-wavelength dependence of the absorption coefficient is developed for temperatures above 200°K.	M. I. Kornfel'd
Research and Development of Germanium PNP Junction Switching Transistors	US Govt Res Repts July 15 1960 LC $4.80 PB 145876	Measurements indicate that reliable hermetic enclosures have resulted.	L. Meretsky
Application of Semiconductor Diodes to Microwave Low-Noise Amplifiers and Harmonic Generators	US Govt Res Repts July 15 1960 LC $10.80 PB 145806	A theory for the maximum achievable voltage gain-fractional bandwidth product of one-port and two-port difference frequency reactance amplifiers has been worked out.	J. C. Greene E. Kraemer et al
Application of Semiconductor Diodes to Microwave Low-Noise Amplifiers and Harmonic Generators	US Govt Res Repts July 15 1960 LC $4.80 PB 145807	Preliminary experimental results are presented on the operation of a microwave third-harmonic generator.	J. C. Greene E. Kraemer et al

SEMICONDUCTOR & SOLID-STATE BIBLIOGRAPHY

TITLE	PUBLICATION	CONDENSED SUMMARY	AUTHORS
Intrinsic-Barrier Transistor Techniques (Silicon)	US Govt Res Repts Aug 19 1960 LC $3.30 PB 146791	The development of design, fabrication, and characterization techniques, is presented for very-high frequency silicon transistors.	J. L. Buie
A Theory for the Transient Analysis of Avalanche Transistor Pulse Circuits	US Govt Res Repts Aug 19 1960 LC $10.80 PB 146426	Minority carrier change variables are used in describing a transistor model.	D. J. Hamilton
Temperature-Resistance Tests of 1N63 and 1N43 Germanium Diodes	US Govt Res Repts Aug 19 1960 LC $1.80 PB 146882	Empirical results available.	G. E. McIntosh
An Alpha Survey Radiac for Field Use	US Govt Res Repts Aug 19 1960 LC $6.30 PB 147376	Equipment uses transistor circuitry.	K. Sinclair G. Kiyoi
Transistor Physics and Electronics Lectures Given Sept 1952-June 1953	US Govt Res Repts Aug 19 1960 LC $66.60 PB 147283	Introductory course lecture notes on transistors and application techniques.	W. H. Duerig J. F. Jenkins, Jr.
An Evaluation of the P-N-P-N Negative Resistance Diode	US Govt Res Repts Aug 19 1960 LC $6.30 PB 146446	The operation of the three-junction diode is analyzed in terms of two contiguous transistors.	H. I. Honor
Transistorized Four-Segment Commutator for a Direct-Current Machine	US Govt Res Repts Aug 19 1960 OTS $1.25 PB 161721	A commutator arrangement using transistors as the switching elements and in the control circuitry.	F. L. Schwartz
The Common Collector-Common Emitter Pair	US Govt Res Repts Aug 19 1960 LC $3.30 PB 146093	The design and analysis of a CC-CE pair in connection with low pass broad band amplifiers.	M. S. Ghausi D. O. Pederson
Transistor-Diode Logic	US Govt Res Repts Aug 19 1960 LC $4.80 PB 146942	A presentation of the design features and discussion of the electrical characteristics of a direct-coupled transistor diode logic circuit.	R. A. Carlsen
Investigation of Duplexing Techniques at High Duty Cycle Conditions	US Govt Res Repts Aug 19 1960 LC $4.80 PB 146795	The analysis of a silicon diffuse junction diode in a microwave circuit is considered as a possible element in a high duty cycle duplexer.	L. Gould
Voltage Sensitive Diode Tuning Systems	US Govt Res Repts Aug 19 1960 LC $4.80 PB 146933	Voltage-sensitive variable-capacitance semiconductor diodes were investigated for use in tuning systems.	R. S. Tilton L. V. Bessen
Engineering Services on Transistors	US Govt Res Repts Aug 19 1960 LC $7.80 PB 147386	Transistor reliability, test methods, and new transmission type transistors.	H. G. Follingstad J. H. Forster
A Transistorized Galvanometer Current Limiter	US Govt Res Repts Aug 19 1960 LC $3.30 PB 146763	A limiter which allows adjustment of the maximum permissible galvanometer current but which has little effect upon the instrumentation system in which it is used.	P. L. Clemens R. L. Ledford
Study of Methods of Cooling Semiconductor Devices	US Govt Res Repts Aug 19 1960 LC $7.70 PB 146874	An investigation of forced convection, and direct and indirect liquid cooling techniques were investigated.	S. K. Morrison J. P. Welsh
Irradiation Testing of Operating Electronic Equipment by Fast Neutrons and Gammas	US Govt Res Repts Aug 19 1960 LC $7.80 PB 147371	Transistorized amplifiers were irradiated in a fast neutron flux, and were found to fail at an integrated flux density of 10^{13} n/cm^2.	R. J. Arndt C. W. Terrell
Thin Films Which Produce Photoelectric and Photoresistive Effects Section I and II (of four sections)	US Govt Res Repts Aug 19 1960 LC $6.30 PB 149950	A presentation of apparatus and measuring techniques for infrared photo conducting devices and, a summary of the electrical and optical properties of PbTe films.	W. Beyen D. Bode
High Temperature Semiconductor Materials and Devices	US Govt Res Repts Aug 19 1960 LC $9.30 PB 147296	A discussion of techniques of preparation of GaAs material and devices.	R. Bube P. R. Celmer
Research and Experimental Work on Microwave Transistors	US Govt Res Repts Aug 19 1960 LC $3.30 PB 146489	Studies of the frequency and power handling capabilities of silicon n-p-n transistors operating as negative resistance oscillators.	W. C. Follmer M. M. Fortini
Micro-Module Production Program	US Govt Res Repts Aug 19 1960 LC $22.80 PB 146042	In micromodule component production, an "in-plastic" sealing technique is used to fabricate transistor units.	P. K. Taylor
Effect of Li-B Ion Pairing on Li^+ Ion Drift in Si	US Govt Res Repts Aug 19 1960 LC $3.30 PB 147359	Ion pairing Li^+ diffusion rate, and the relation between them in silicon are measured and discussed.	E. M. Pell
Electron Mobility and Scattering Process In AgBr at Low Temperatures	US Govt Res Repts Aug 19 1960 LC $7.80 PB 146930	A study of Hall effect for electrons released by light in high purity crystals in the temperature range 4°K to 120°K.	D. C. Burnham F. C. Brown

Market News . . .

Sales

EIA has estimated that plant sales of semiconducotrs for 1960 will surpass the half billion dollar level as compared with the $377 million in 1959. The expected increase will be 43% in transistors and 35% in diodes and rectifiers. Figures on factory sales are:

	First 9 mos. 1959	First 9 mos. 1960	1959	1960 (estimated)
	Millions of Dollars			
Transistors	$154.3	$222.2	$222.0	$317.0
Diodes & Rectifiers*	96.7	131.9	155.0	210.0
Total	$251.0	$354.1	$377.0	$527.0
	Millions of Units			
Transistors	57.9	90.3	82.3	129.9
Diodes & Rectifiers*	—	—	—	—

* Excludes Zener Diodes which accounted for $11 million in 1959 and will probably surpass $20 million in Factory Sales during 1960.

According to statistics released by the Marketing Data Department of the Electronic Industries Association, factory sales of transistors during October declined under the year's high total set in September, but remained above the 12-million mark for the second month in a row. The latest compilation follows:

	Factory Sales (Units)	Factory Sales (Dollars)
October	12,168,632	$25,945,195
September	12,973,792	28,442,229
August	9,732,993	22,739,969
July	7,070,884	18,083,802
June	10,392,412	27,341,733
May	9,046,237	24,146,373
April	9,891,236	23,198,576
March	12,021,506	28,700,129
February	9,527,662	24,831,570
January	9,606,630	24,714,580
Jan.-Oct. '60 Totals	102,431,984	248,144,156
Jan.-Oct. '59 Totals	74,467,926	199,189,791

The Commerce Department's Electronics division has reported that exports of crystal diodes and transistors for the first nine months of 1960 were $11,729,000 as compared with $6,461,000 in the same period in 1959.

Texas Instruments Incorporated has established a new sales engineering apparatus office in Wellesley, Mass., their third such office in the east.

Avnet Electronics Corp. has opened a new sales engineering office and service center facility in Seattle, Wash., and in Salt Lake City, Utah. The company has other such offices in Westbury, N.Y.; Burlington, Mass.; Dayton, O.; Chicago, Los Angeles and Sunnyvale, Cal.

General Electric Company announces the creation of a Southeastern Sales Region by its Semiconductor Products Department in Washington, D.C., to serve 10 states and the District of Columbia.

Prices

Hughes Aircraft Co.'s Semiconductor division has established a new price schedule for its silicon transistors calling for reductions from $9 to $19 per unit in 1-99 quantities. These reductions apply to their high speed mesa units, silicon alloy transistors and high frequency mil-spec mesa transistors. Prices have also been established on their new alloy-junction medium-speed transistors. They are each priced as follows: 2N327A at $5.20; 2N328A at $7.80, and 2N329A at $15.60, all in quantities up to 99 units.

R.C.A., Somerville, N.J. is producing a family of seven diffused-junction mesa gallium arsenide varactor diodes. Designated as XVD100 through XVD106 they are priced from $200 to $700 each.

Philco Corp.'s Lansdale Division, Semiconductor Operations, has developed a new silicon precision alloy transistor (SPAT) of the *p-n-p* type. Eight different types designated T-2050 to T-2071 will be available at prices ranging from $5.70 to $9.90 in quantities of 1000 or more.

Alloys Unlimited Chemicals, Inc., a division of Alloys Unlimited Inc., N.Y. is producing single and polycrystal gallium arsenide. This material is available in highly doped forms using zinc, cadmium and manganese as doping agents for *p*-type material and tellurium for *n*-type material. Prices of single crystal GaAs is $20 per gram in quantities of 20-99 grams; $14 in quantities for 100-999 grams, and $8.75 for 1000 grams. Polycrystalline prices are $6.75; $6.50, and $6.00 a gram for the same quantity scale.

Suppliers.

The Chemicals and Metals division of the Eagle Picher Co. has expanded its line of electronic metals and compounds with the addition of 16 new materials. These include inter-metallics special electronic compounds, ultra high purity cadmium and germanium compounds, gallium arsenide and other high purity elements.

Alpha Metals, Inc., Jersey City, N.J., has made available 99.999% pure indium. Their semiconductor grade indium contains less than 1 part in each million of either silver or copper. Tin and lead content is less than 3 parts per million each. Other elements are not detected by spectrographic analysis. It is available in bars or special shapes.

Distributors

Standard Rectifier Corp. has named the following four additional distributors: Lafayette Radio Corp., Boston; Almo Radio Co., Philadelphia; Hollywood Radio & Electronics, Hollywood; and Terminal-Hudson Radio Co., New York.

General Instrument Corp., has established a new distributor organization for setting up a network of industrial distributors to handle their full line of transistors, diodes and rectifiers. The firm now has about 70 distributors.

Financial

Cetron Electronic Corporation of Geneva, Ill., and Pasadena, Calif., told its shareholders at the company's first annual meeting recently in Geneva that sales are expected to triple, with an accompanying favorable trend in earnings, during the fiscal year ending next November 30. Now doing business at the annual rate of just under $1 million, one of the reasons that the company will not show earnings for the fiscal year ended November 30, 1960, is because of a substantial investment in the new scientific optical division.

Expansions

General Electric Co. has established a signal diode project within its Semiconductor Products department in anticipation of increased tunnel diode sales estimated at 100 million by 1965.

General Instrument Corp., has opened a $3 million 50,000 square foot plant on a nine acre site in Hicksville, L.I., N.Y., for the development and production of semiconductors. This plant will be producing ultra-high speed switching transistors, tunnel diodes, germanium MADT transistors, silicon mesa transistors, solar cells and microcircuits.

Accurate Specialties Co., Inc. has opened a modern 15,000 square foot plant in Hackensack, N.J. This new facility will permit a 30% increase in their production lines for the manufacture of semiconductor preform discs and washers, clad metal base tab stampings, and spheres. In this same facility, they are setup to produce the raw materials, including their rolling mills for manufacture of precision strip and clad metals.

Tang Industries, Inc., Waltham, Mass., has been reorganized because of recent developments in materials processing. Besides work on transistors, diodes and rectifiers, Tang, with its subsidiaries, will explore micro-electronics applications, energy conversion devices, transducers, and thermaelectric devices.

General Electric Co., is considering expansion of its transistor plant in Buffalo, N.Y.

Rheem Manufacturing Company has taken a 20-year lease on a new 100,000-square-foot building at Mountain View, Calif. for its subsidiary, Rheem Semiconductor Corporation, in a sale and leaseback arrangement with the New England Mutual Life Insurance Company for a consideration of $2 million.

CHARACTERISTICS CHARTS OF NEW DIODES and RECTIFIERS

MANUFACTURERS

AEG—	Allgemeine Elekticitats-Gesellschaft
ASC—	American Semiconductor Corp.
AMP—	Amperex Electronic Corp.
AEI—	Associated Electrical Industries, Ltd.
BEN—	Bendix Corp.
BER—	Berkshire Corp.
BOM—	Bomac Labs
BRA—	Bradley Semiconductor Corp.
BRI—	Britton Electronics Corp.
CBS—	CBS Electronics
CDC—	Continental Device Corp.
COD—	Computer Diode Corp.
COL—	Columbus Electronics Corp.
CON—	Controls Co., of America
CTP—	Clevite Transistor Products, Inc.
CSF—	(Cosem) Cie Generale des Semi-Conducteurs
DEL—	Delco Radio
DIC—	Dickson Electronics Corp.
EEVB—	English Electric Valve Co., Ltd.
ERI—	Erie Resistor Corp.
ESP—	Espey Mfg. and Electronics Corp.
FAN—	Fansteel Metallurgical Corp.
FERB—	Ferranti Ltd.
FSC—	Fairchild Semiconductor Corp.
GAH—	Gahagan, Inc.
GECB—	General Electric Co., Ltd.
GE—	General Electric Company, Semiconductor Div.
GELC—	Canadian General Electric Co.
GIC—	General Instrument Corp.
HAFO—	Institutet for Halvedarforskning
HSD—	Hoffman Semiconductor Division
HITJ—	Hitachi Ltd., Mushashi Works
HUG—	Hughes Products Division
ITC—	Industro Transistor Corp.
INRB—	International Rectifier Co., Ltd.
INRC—	International Rectifier Corp.
IRC—	International Resistance Co.
ITT—	International Tel. & Tel. Corp.
KEM—	Kemtron Electron Products, Inc.
MATJ—	P. R. Mallory & Co.. Inc.
MAL—	Matushita Electronics Corp.
MIC—	Microwave Associates, Inc.
MISI—	Mistral
MOT—	Motorola, Inc
MUL—	Mullard, Ltd.
NAE—	North American Electronics
NPC—	Nucleonic Products Co., Inc.
OHI—	Ohio Semiconductor Inc.
OHM—	Ohmite Manufacturing Co.
PHI—	Philco Corp. Lansdale Div., Semiconductor Operations
PHIN—	Philips Gloeilampenfabrieken
PLEB—	The Plessey Co.
PSI—	Pacific Semiconductors, Inc.
QSC—	International Diode Corp.
RADF—	La Radiotechnique Div. Tubes Electroniques
RAY—	Raytheon Company
RCA—	Radio Corporation of America, Semiconductor Div.
RDR—	Radio Development and Research Corp.
RHE—	Rheem Semiconductor Corp.
ROSG—	Dr. Ing. Rudolph Rost
SAR—	Sarkes Tarzian, Inc., Rectifier Division
SCN—	Semicon, Inc.
SEM—	Semi-Elements Inc.
SIE—	Siemens & Halske Aktiengesellschaft
SIL—	Silicon Transistor Corp.
SOIF—	Societe Industrial de Liaisons
SONY—	Sony Corp.
SSD—	Sperry Semiconductor Division
SSP—	Solid State Products, Inc.
STC—	Shockley Transistor Corp.
STCB—	Standard Telephone & Cables, Ltd.
SYL—	Sylvania Electric Products, Inc.
SYN—	Syntron Co.
TEX—	Texas Research Assoc.
TFKG—	Telefunken, Ltd.
TI—	Texas Instruments Incorporated
TKD—	Tekade
TOK—	Tokyo Tsushin Kogyo, Ltd.
TRA—	Transitron Electronic Corp.
TUN—	Tung-Sol Electric, Inc.
TSC—	Trans-Sil Corp.
UCI—	United Components
USD—	United States Dynamics Corp.
UNI—	Unitrode Transistor Prods., Corp.
USS—	U. S. Semiconductor Products, Inc.
VIC—	Vickers Inc.
WEC—	Western Electric Co.
WEST—	Westinghouse Electric Corp.

CHARACTERISTICS CHART of SILICON ZENER or AVALANCHE DIODES

TYPE NO.	Zener or Avalanche Voltage Range MIN. E_{b1} (volts)	MAX. E_{b2} (volts)	@ I_z (ma)	Dynamic Impedance Z @ I_z (ohms)	(ma)	MAX. DISS. (mw)	TEMP. CO-EFFICIENT %/°C	MFR. (See code at start of chart)
3/4Z5.8D Δ	5.4	8.2	37	3.5	37	750	.040	DIC
3/4Z7.5D Δ	6.0	9.0	34	4.0	34	750	.045	DIC
3/4Z8.2D Δ	6.6	9.8	31	4.5	31	750	.048	DIC
3/4Z9.1D Δ	7.3	10.9	28	5.0	28	750	.051	DIC
3/4Z10D Δ	8.0	12	25	7.0	25	750	.055	DIC
3/4Z11D Δ	8.8	13.2	23	8.0	23	750	.060	DIC
3/4Z12D Δ	9.6	14.4	21	9.0	21	750	.065	DIC
3/4Z13D Δ	10.4	15.6	19	10	19	750	.065	DIC
3/4Z14D Δ	11.2	16.8	18	12	18	750	.070	DIC
3/4Z15D Δ	12	18	17	14	17	750	.070	DIC
3/4Z16D Δ	12.8	19.2	15.5	16	15.5	750	.070	DIC
3/4Z17D Δ	13.6	20.4	14.5	18	14.5	750	.075	DIC
3/4Z18D Δ	14.4	21.6	14	20	14	750	.075	DIC
3/4Z19D Δ	15.2	22.8	13	21	13	750	.075	DIC
3/4Z20D Δ	16	24	12.5	22	12.5	750	.075	DIC
3/4Z22D Δ	17.6	26.4	11.5	23	11.5	750	.080	DIC
3/4Z24D Δ	19.2	28.8	10.5	25	10.5	750	.080	DIC
3/4Z25D Δ	20	30	10	30	10	750	.080	DIC
3/4Z27D Δ	21.6	32.4	9.5	35	9.5	750	.085	DIC
3/4Z30D Δ	24	36	8.5	40	8.5	750	.085	DIC
3/4Z33D Δ	26.4	39.6	7.5	46	7.5	750	.085	DIC
3/4Z36D Δ	28.8	43.2	7.0	50	7.0	750	.085	DIC
3/4Z39D Δ	31.2	46.8	6.5	60	6.5	750	.090	DIC
3/4Z43D Δ	34.4	51.6	6.0	70	6.0	750	.090	DIC
3/4Z45D Δ	36	54	5.5	75	5.5	750	.090	DIC
3/4Z47D Δ	37.6	56.4	5.5	80	5.5	750	.090	DIC
3/4Z50D Δ	40	60	5.0	90	5.0	750	.090	DIC
3/4Z51D Δ	40.8	61.2	5.0	95	5.0	750	.090	DIC
3/4Z52D Δ	41.6	62.4	5.0	100	5.0	750	.090	DIC
3/4Z56D Δ	44.8	67.2	4.5	110	4.5	750	.090	DIC
3/4Z62D Δ	49.6	74.4	4.0	125	4.0	750	.090	DIC
3/4Z68D Δ	54.4	81.6	3.7	150	3.7	750	.090	DIC
3/4Z75D Δ	60	90	3.3	175	3.3	750	.090	DIC
3/4Z82D Δ	65.6	98.4	3.0	200	3.0	750	.090	DIC
3/4Z91D Δ	73	109	2.8	250	2.8	750	.090	DIC
3/4Z100D Δ	80	120	2.5	350	2.5	750	.090	DIC
3/4Z105D Δ	84	126	2.5	400	2.5	750	.095	DIC
3/4Z110D Δ	88	132	2.3	450	2.3	750	.095	DIC
3/4Z120D Δ	96	144	2.0	550	2.0	750	.095	DIC
3/4Z130D Δ	104	156	1.9	700	1.9	750	.095	DIC

CHARACTERISTICS CHART of SILICON ZENER or AVALANCHE DIODES

TYPE NO.	Zener or Avalanche Voltage Range MIN. E_{b1} (volts)	MAX. E_{b2} (volts)	@ I_z (ma)	Dynamic Impedance Z @ I_z (ohms)	(ma)	MAX. DISS. (mw)	TEMP. CO-EFFICIENT %/°C	MFR. (See code at start of chart)
1.5Z9.1D Δ	7.3	10.9	41	4.0	41	1500	.051	DIC
1.5Z10D Δ	8.0	12	37	5.0	37	1500	.055	DIC
1.5Z11D Δ	8.8	13.2	34	6.0	34	1500	.060	DIC
1.5Z12D Δ	9.6	14.4	31	7.0	31	1500	.065	DIC
1.5Z13D Δ	10.4	15.6	29	8.0	29	1500	.065	DIC
1.5Z14D Δ	11.2	16.8	26	9.0	26	1500	.070	DIC
1.5Z15D Δ	12	18	25	10	25	1500	.070	DIC
1.5Z16D Δ	12.8	19.2	23	11	23	1500	.070	DIC
1.5Z17D Δ	13.6	20.4	22	12	22	1500	.075	DIC
1.5Z18D Δ	14.4	21.6	21	13	21	1500	.075	DIC
1.5Z19D Δ	15.2	22.8	20	14	20	1500	.075	DIC
1.5Z20D Δ	16	24	19	15	19	1500	.075	DIC
1.5Z22D Δ	17.6	26.4	17	16	17	1500	.080	DIC
1.5Z24D Δ	19.2	28.8	16	17	16	1500	.080	DIC
1.5Z25D Δ	20	30	15	18	15	1500	.080	DIC
1.5Z27D Δ	21.6	32.4	14	20	14	1500	.085	DIC
1.5Z30D Δ	24	36	12	25	12	1500	.085	DIC
1.5Z33D Δ	26.4	39.6	11	30	11	1500	.085	DIC
1.5Z36D Δ	28.8	43.2	10	35	10	1500	.085	DIC
1.5Z39D Δ	31.2	46.8	10	40	10	1500	.090	DIC
1.5Z43D Δ	34.4	51.6	9.0	45	9.0	1500	.090	DIC
1.5Z45D Δ	36	54	8.5	50	8.5	1500	.090	DIC
1.5Z47D Δ	37.6	56.4	8.0	55	8.0	1500	.090	DIC
1.5Z50D Δ	40	60	7.5	60	7.5	1500	.090	DIC
1.5Z51D Δ	40.8	61.2	7.3	60	7.3	1500	.090	DIC
1.5Z52D Δ	41.6	62.4	7.2	65	7.2	1500	.090	DIC
1.5Z56D Δ	44.8	67.2	6.7	75	6.7	1500	.090	DIC
1.5Z62D Δ	49.6	74.4	6.0	85	6.0	1500	.090	DIC
1.5Z68D Δ	54.4	81.6	5.5	95	5.5	1500	.090	DIC
1.5Z75D Δ	60	90	5.0	110	5.0	1500	.090	DIC
1.5Z82D Δ	65.6	98.4	4.5	130	4.5	1500	.090	DIC
1.5Z91D Δ	73	109	4.1	150	4.1	1500	.090	DIC
1.5Z100D Δ	80	120	3.7	200	3.7	1500	.090	DIC
1.5Z105D Δ	84	126	3.5	250	3.5	1500	.095	DIC
1.5Z110D Δ	88	132	3.4	300	3.4	1500	.095	DIC
1.5Z120D Δ	96	144	3.1	350	3.1	1500	.095	DIC
1.5Z130D Δ	104	156	2.9	400	2.9	1500	.095	DIC
1.5Z140D Δ	112	168	2.7	600	2.7	1500	.095	DIC
1.5Z150D Δ	120	180	2.5	700	2.5	1500	.095	DIC
1.5Z160D Δ	128	192	2.3	750	2.3	1500	.095	DIC

1T8.2	7.38	9.02	100	2.4	100	1000		
1T9.1	8.09	10.01	50	3.0	50	1000		SAR
1T10	9.0	11	50	3.5	50	1000		SAR
1T11	9.99	12.1	50	4.2	50	1000		SAR
1T12	10.8	13.2	50	5.0	50	1000		SAR
1T13	11.7	14.3	50	5.8	50	1000		SAR
1T15	13.5	16.5	50	7.6	50	1000		SAR
1T16	14.4	17.6	50	8.6	50	1000		SAR
1T18	16.2	19.8	50	11	50	1000		SAR
1T20	18	22	15	13	15	1000		SAR
1T22	19.8	24.2	15	16	15	1000		SAR
1T24	21.6	26.2	15	18	15	1000		SAR
1T27	24.3	29.7	15	23	15	1000		SAR
1T30	27	33	15	28	15	1000		SAR
1T33	29.7	36.3	15	33	15	1000		SAR
1T36	32.4	39.6	15	39	15	1000		SAR
1T39	35.1	42.9	15	45	15	1000		SAR
1T43	38.7	47.3	15	54	15	1000		SAR
1T47	42.3	51.7	15	64	15	1000		SAR
1T51	45.9	56.1	15	74	15	1000		SAR
1T56	50.4	61.6	15	88	15	1000		SAR
1T62	55.8	68.2	5.0	105	5.0	1000		SAR
1T68	61.2	74.8	5.0	125	5.0	1000		SAR
1T75	67.5	82.5	5.0	150	5.0	1000		SAR
1T82	73.8	90.2	5.0	175	5.0	1000		SAR
1T91	81.9	100.1	5.0	220	5.0	1000		SAR
1T100	90	110	5.0	260	5.0	1000		SAR
1Z6.8D Δ	5.4	8.2	37	3.5	37	1000	.040	DIC
1Z7.5D Δ	6.0	9.0	34	4.0	34	1000	.045	DIC
1Z8.2D Δ	6.6	9.8	31	4.5	31	1000	.048	DIC
1Z9.1D Δ	7.3	10.9	28	5.0	28	1000	.051	DIC
1Z10D Δ	8.0	12	25	7.0	25	1000	.055	DIC
1Z11D Δ	8.8	13.2	23	8.0	23	1000	.060	DIC
1Z12D Δ	9.6	14.4	21	9.0	21	1000	.065	DIC
1Z13D Δ	10.4	15.6	19	10	19	1000	.065	DIC
1Z14D Δ	11.2	16.8	18	12	18	1000	.070	DIC
1Z15D Δ	12	18	17	14	17	1000	.070	DIC
1Z16D Δ	12.8	19.2	15.5	16	15.5	1000	.070	DIC
1Z17D Δ	13.6	20.4	14.5	18	14.5	1000	.075	DIC
1Z18D Δ	14.4	21.6	14	20	14	1000	.075	DIC
1Z19D Δ	15.2	22.8	13	21	13	1000	.075	DIC
1Z20D Δ	16	24	12.5	22	12.5	1000	.075	DIC
1Z22D Δ	17.6	26.4	11.5	23	11.5	1000	.080	DIC
1Z24D Δ	19.2	28.8	10.5	25	10.5	1000	.080	DIC
1Z25D Δ	20	30	10	30	10	1000	.080	DIC
1Z27D Δ	21.6	32.4	9.5	35	9.5	1000	.085	DIC
1Z30D Δ	24	36	8.5	40	8.5	1000	.085	DIC
1Z33D Δ	26.4	39.6	7.5	45	7.5	1000	.085	DIC
1Z36D Δ	28.8	43.2	7.0	50	7.0	1000	.085	DIC
1Z39D Δ	31.2	46.8	6.5	60	6.5	1000	.090	DIC
1Z43D Δ	34.4	51.6	6.0	70	6.0	1000	.090	DIC
1Z45D Δ	36	54	5.5	75	5.5	1000	.090	DIC
1Z47D Δ	37.6	56.4	5.5	80	5.5	1000	.090	DIC
1Z50D Δ	40	60	5.0	90	5.0	1000	.090	DIC
1Z51D Δ	40.8	61.2	5.0	95	5.0	1000	.090	DIC
1Z52D Δ	41.6	62.4	5.0	100	5.0	1000	.090	DIC
1Z56D Δ	44.8	67.2	4.5	110	4.5	1000	.090	DIC
1Z62D Δ	49.6	74.4	4.0	125	4.0	1000	.090	DIC
1Z68D Δ	54.4	81.6	3.7	150	3.7	1000	.090	DIC
1Z75D Δ	60	90	3.3	175	3.3	1000	.090	DIC
1Z82D Δ	65.6	98.4	3.0	200	3.0	1000	.090	DIC
1Z91D Δ	73	109	2.8	250	2.8	1000	.090	DIC
1Z100D Δ	80	120	2.5	350	2.5	1000	.090	DIC
1Z105D Δ	84	126	2.5	400	2.5	1000	.095	DIC
1Z110D Δ	88	132	2.3	450	2.3	1000	.095	DIC
1Z120D Δ	96	144	2.0	550	2.0	1000	.095	DIC
1Z130D Δ	104	156	1.9	700	1.9	1000	.095	DIC
1Z140D Δ	112	168	1.8	900	1.8	1000	.095	DIC
1Z150D Δ	120	180	1.7	1000	1.7	1000	.095	DIC
1Z160D Δ	128	192	1.6	1100	1.6	1000	.095	DIC
1Z175D Δ	140	210	1.4	1200	1.4	1000	.095	DIC
1Z180D Δ	143	216	1.4	1200	1.4	1000	.095	DIC
1Z200D Δ	160	240	1.2	1500	1.2	1000	.100	DIC
1.5Z6.8D Δ	5.4	8.2	55	2.7	55	1500	.040	DIC
1.5Z7.5D Δ	6.0	9.0	50	3.0	50	1500	.045	DIC
1.5Z8.2D Δ	6.6	9.8	46	3.5	46	1500	.048	DIC

10Z13D Δ	10.4	15.6	190	3.0	190	10W	.065	DIC
10Z14D Δ	11.2	16.8	180	3.0	180	10W	.070	DIC
10Z15D Δ	12	18	170	3.0	170	10W	.070	DIC
10Z16D Δ	12.8	19.2	155	4.0	155	10W	.070	DIC
10Z17D Δ	13.6	20.4	145	4.0	145	10W	.075	DIC
10Z18D Δ	14.4	21.6	140	4.0	140	10W	.075	DIC
10Z19D Δ	15.2	22.8	130	4.0	130	10W	.075	DIC
10Z20D Δ	16	24	125	4.0	125	10W	.075	DIC
10Z22D Δ	17.6	26.4	115	5.0	115	10W	.080	DIC
10Z24D Δ	19.2	28.8	105	5.0	105	10W	.080	DIC
10Z25D Δ	20	30	100	6.0	100	10W	.080	DIC
10Z27D Δ	21.6	32.4	95	7.0	95	10W	.085	DIC
10Z30D Δ	24	36	85	8.0	85	10W	.085	DIC
10Z33D Δ	26.4	39.6	75	9.0	75	10W	.085	DIC
10Z36D Δ	28.8	43.2	70	10	70	10W	.085	DIC
10Z39D Δ	31.2	46.8	65	11	65	10W	.090	DIC
10Z43D Δ	34.4	51.6	60	12	60	10W	.090	DIC
10Z45D Δ	36	54	55	13	55	10W	.090	DIC
10Z47D Δ	37.6	56.4	55	14	55	10W	.090	DIC
10Z50D Δ	40	60	50	15	50	10W	.090	DIC
10Z51D Δ	40.8	61.2	50	15	50	10W	.090	DIC
10Z52D Δ	41.6	62.4	50	15	50	10W	.090	DIC
10Z56D Δ	44.8	67.2	45	16	45	10W	.090	DIC
10Z62D Δ	49.6	74.4	40	17	40	10W	.090	DIC
10Z68D Δ	54.4	81.6	37	18	37	10W	.090	DIC
10Z75D Δ	60	90	33	22	33	10W	.090	DIC
10Z82D Δ	65.6	98.4	30	25	30	10W	.090	DIC
10Z91D Δ	73	109	28	35	28	10W	.090	DIC
10Z100D Δ	80	120	25	40	25	10W	.090	DIC
10Z105D Δ	84	126	25	45	25	10W	.095	DIC
10Z110D Δ	88	132	23	55	23	10W	.095	DIC
10Z120D Δ	96	144	20	75	20	10W	.095	DIC
10Z130D Δ	104	156	19	100	19	10W	.095	DIC
10Z140D Δ	112	168	18	125	18	10W	.095	DIC
10Z150D Δ	120	180	17	175	17	10W	.095	DIC
10Z160D Δ	128	192	16	200	16	10W	.095	DIC
10Z175D Δ	140	210	14	250	14	10W	.095	DIC
10Z180D Δ	143	216	14	260	14	10W	.095	DIC
10Z200D Δ	160	240	12	300	12	10W	.100	DIC
DZ10A	9.1	11	20	13	20	500	.055	SOIF
DZ10B	91	110	2.0	430	2.0	500	.090	SOIF
DZ12A	11	13	16	18	16	500	.065	SOIF
DZ15A	13	16	13	24	13	500	.070	SOIF
DZ18A	15	20	11	33	11	500	.075	SOIF
DZ22A	20	24	9.1	43	9.1	500	.080	SOIF
DZ27A	24	30	7.5	56	7.5	500	.085	SOIF
DZ33A	30	36	6.2	75	6.2	500	.085	SOIF
DZ39A	36	43	5.1	100	5.1	500	.090	SOIF
DZ47A	43	51	4.3	130	4.3	500	.090	SOIF
DZ56A	51	62	3.6	180	3.6	500	.090	SOIF
DZ68A	62	75	3.0	240	3.0	500	.090	SOIF
DZ82A	75	91	2.4	330	2.4	500	.090	SOIF
MZ7.5BCA	7.1	7.9	335	250	1.0	10W	.045	USS
MZ8.2BCA	7.8	8.6	305	250	1.0	10W	.048	USS
MZ9.1BCA	8.6	9.6	275	250	1.0	10W	.051	USS
MZ10BFA	9.5	10.5	250	250	1.0	10W	.055	USS
MZ11BDA	10.4	11.6	230	250	1.0	10W	.060	USS
MZ12BFA	11.4	12.6	210	250	1.0	10W	.065	USS
MZ13BDA	12.3	13.7	190	250	1.0	10W	.065	USS
MZ14BBA	13.3	14.7	180	250	1.0	10W	.070	USS
MZ15BFA	14.2	15.8	170	250	1.0	10W	.070	USS
MZ16BDA	15.1	16.9	155	250	1.0	10W	.070	USS
MZ17BBA	16.1	17.9	145	250	1.0	10W	.075	USS
MZ18BFA	17.1	18.9	140	250	1.0	10W	.075	USS
MZ19BBA	18	20	130	250	1.0	10W	.075	USS
MZ20BDA	19	21	125	250	1.0	10W	.075	USS
MZ22BFA	20.9	23.1	115	250	1.0	10W	.080	USS
MZ24BDA	22.8	25.2	105	250	1.0	10W	.080	USS
MZ25BBA	23.7	26.3	100	250	1.0	10W	.080	USS
MZ27BFA	25.6	28.4	95	250	1.0	10W	.085	USS
MZ30BDA	28.5	31.5	85	300	1.0	10W	.085	USS
MZ33BDA	31.3	34.7	75	300	1.0	10W	.085	USS
MZ36BDA	34.2	37.8	70	300	1.0	10W	.085	USS
MZ39BDA	36.1	42.9	65	300	1.0	10W	.090	USS
MZ43BDA	40.8	45.2	60	400	1.0	10W	.090	USS
MZ45BBA	42.7	47.3	55	400	1.0	10W	.090	USS
MZ47BDA	44.6	49.4	55	400	1.0	10W	.090	USS
MZ50BBA	47.5	52.5	50	500	1.0	10W	.090	USS
MZ52BBA	48.4	54.6	50	500	1.0	10W	.090	USS
MZ56BDA	53.2	58.8	45	500	1.0	10W	.090	USS
MZ62BDA	58.9	65.1	40	600	1.0	10W	.090	USS
MZ68BDA	64.6	71.4	37	600	1.0	10W	.090	USS
MZ75BDA	71.2	78.8	33	600	1.0	10W	.090	USS
MZ82BDA	77.9	86.1	30	700	1.0	10W	.090	USS
MZ91BDA	86.4	95.6	28	800	1.0	10W	.090	USS

UNDER TYPE NO.

∅ - Revised Specifications Δ - Also available with ±5 per cent tolerance
Ø - Double Anode Type † - Reference Amplifier
* - Developmental Type # - Available with reverse polarity

CHARACTERISTICS CHART of SILICON ZENER or AVALANCHE DIODES

TYPE NO.	Zener or Avalanche Voltage Range MIN. Eb1 (volts)	MAX. Eb2 (volts)	@ Iz (ma)	Dynamic Impedance Z @ Iz (ohms)	(ma)	MAX. DISS. (mw)	TEMP. CO-EFFICIENT %/°C	MFR. (See code at start of chart)
MZ100BDA	95	105	25	900	1.0	10W	.090	USS
MZ105BB	94.5	115.5	25	1000	1.0	10W	.095	USS
MZ110BD	99	121	23	1100	1.0	10W	.095	USS
MZ120BD	108	132	20	1200	1.0	10W	.095	USS
MZ130BD	117	143	19	1300	1.0	10W	.095	USS
MZ140BB	126	154	18	1400	1.0	10W	.095	USS
MZ150BD	135	165	17	1500	1.0	10W	.095	USS
MZ175BB	157.5	192.5	14	1750	1.0	10W	.095	USS
MZ200BC	180	220	12	2000	1.0	10W	.100	USS
PZ10A	9.1	11	200	1.3	200	10W	.055	SOIF
PZ10B	91	110	20	43	20	10W	.090	SOIF
PZ12A	11	13	160	1.8	160	10W	.065	SOIF
PZ15A	13	16	130	2.4	130	10W	.070	SOIF
PZ18A	16	20	110	3.3	110	10W	.075	SOIF
PZ22A	20	24	91	4.3	91	10W	.080	SOIF
PZ27A	24	30	75	5.6	75	10W	.085	SOIF
PZ33A	30	36	62	7.5	62	10W	.085	SOIF
PZ39A	36	43	51	10	51	10W	.090	SOIF
PZ47A	43	51	43	13	43	10W	.090	SOIF
PZ56A	51	62	36	18	36	10W	.090	SOIF
PZ68A	62	75	30	24	30	10W	.090	SOIF
PZ82A	75	91	24	33	24	10W	.090	SOIF
RZ10A	9.1	11	390	1.3	390	20W	.055	SOIF
RZ10B	91	110	39	43	39	20W	.090	SOIF
RZ12A	11	13	330	1.8	330	20W	.065	SOIF
RZ15A	13	16	270	2.4	270	20W	.070	SOIF
RZ18A	16	20	220	3.3	220	20W	.075	SOIF
RZ22A	20	24	180	4.3	180	20W	.080	SOIF
RZ27A	24	30	150	5.6	150	20W	.080	SOIF
RZ33A	30	36	120	7.5	120	20W	.085	SOIF
RZ39A	36	43	100	10	100	20W	.085	SOIF
RZ47A	43	51	82	13	82	20W	.090	SOIF
RZ56A	51	62	68	18	68	20W	.090	SOIF
RZ68A	62	75	56	24	56	20W	.090	SOIF
RZ82A	75	91	47	33	47	20W	.090	SOIF

UNDER TYPE NO.
∅ - Revised Specifications
Ø - Double Anode Type
* - Developmental Type
△ - Also available with ±5 per cent tolerance
† - Reference Amplifier
# - Available with reverse polarity

DIODES and RECTIFIERS

UNDER USE
1 - General Purpose
2 - Power Rectifier
3 - Magnetic Amplifier
5 - Controlled Rectifier
6 - Dual Rectifier
7 - Controlled Forward Conductance
8 - High Voltage Rectifier
9 - Bridge Rectifier
∅ - Revised Specifications
Ø - Insulated Base
△ - Direct Tube Replacement
† - Pair
# - Forced Air Cooling

OTHER
4 - For half wave resistance lead average over 1 cycle

REVERSE CURRENT
∅ - Dynamic

MFR
6 - Available in Stack form from Mfr.

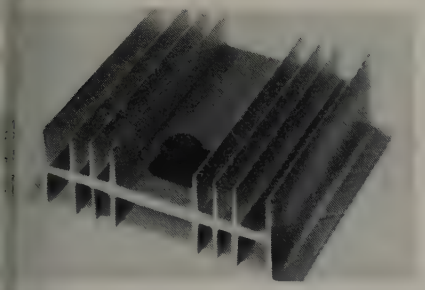
FOLLOWING ANY TEMPERATURE READING
A - Ambient
C - Case
J - Junction
S - Storage
△ - Inlet temperature of coolant

CHARACTERISTICS CHART of DIODES and RECTIFIERS

TYPE NO.	USE (See Code Below)	MAT	PIV (volts)	MAX. CONT. WORK. VOLT. (volts)	Min. Forward Current @ 25°C If @ Ef (mA)	(volts)	MAX. D.C. OUTPUT CURRENT[4] @ T (°C) (amps)	MAX. FULL LOAD VOLT. DROP[4] (volts)	Max. Rev. Current Ib @ Eb @ T (uA)	(volts)	(°C)	MFR. (See code at start of charts)
P6006	2,3	S1	750	600	6000	1.2	6.0	125C	.60	3000∅	600	125C	SOIF-6
R8H	2,3	S1	1000	800	15A	1.2	10	125C	.60	3000∅	800	125C	SOIF-6
R1015	2,3	S1	125	100	15A	1.2	15	125C	.60	3000∅	100	125C	SOIF-6
R1020	2,3	S1	125	100	20A	1.1	20	125C	.60	3000∅	100	125C	SOIF-6
R2015	2,3	S1	250	200	15A	1.2	15	125C	.60	3000∅	200	125C	SOIF-6
R2020	2,3	S1	250	200	20A	1.1	20	125C	.60	3000∅	200	125C	SOIF-6
R4015	2,3	S1	500	400	15A	1.2	15	125C	.60	3000∅	400	125C	SOIF-6
R4020	2,3	S1	500	400	20A	1.1	20	125C	.60	3000∅	400	125C	SOIF-6
R6015	2,3	S1	750	600	15A	1.2	15	125C	.60	3000∅	600	125C	SOIF-6
S1006	2,3	S1	125	100	60A	1.1	60	125C	.60	5000∅	100	125C	SOIF-6
S2006	2,3	S1	250	200	60A	1.1	60	125C	.60	5000∅	200	125C	SOIF-6
S4006	2,3	S1	500	400	60A	1.1	60	125C	.60	5000∅	400	125C	SOIF-6
S6006	2,3	S1	750	600	60A	1.1	60	125C	.60	5000∅	600	125C	SOIF-6
S101F	2	S1	300	160			.60	50A	.60	800		140J	AEG
S101K	2	S1	600	380			.60	50A	.60	800		140J	AEG
S103F	2	S1	300	160			2.5	50A	.60	500		140J	AEG
S103K	2	S1	600	380			2.5	50A	.60	500		140J	AEG
S111F	2	S1	300	160			10	50A	.60	3000		140J	AEG
S111K	2	S1	600	380			10	50A	.60	3000		140J	AEG
S121F	2	S1	300	160			20	50A	.60	6000		140J	AEG
S121K	2	S1	600	380			20	50A	.60	6000		140J	AEG
S141F	2,#	S1	300	160			90	50A	.65	10ma		140J	AEG
S141K	2,#	S1	600	380			90	50A	.65	10ma		140J	AEG
S191F	2,#	S1	300	160			200	50A	.65	20ma		140J	AEG
S191K	2,#	S1	600	380			200	50A	.65	20ma		140J	AEG
SJ051F	2	S1	50	50			.70	25A	1.7	500	50	120J	AEI
SJ052F	2	S1	50	50			1.0	25A	1.7	1500	50	200J	AEI
SJ101F	2	S1	100	100			.70	25A	1.7	500	100	120J	AEI
SJ102F	2	S1	100	100			1.0	25A	1.7	1500	100	200J	AEI
SJ201F	2	S1	200	200			.70	25A	1.7	500	200	120J	AEI
SJ202F	2	S1	200	200			1.0	25A	1.7	1500	200	200J	AEI
SJ301F	2	S1	300	300			.70	25A	1.7	500	300	120J	AEI
SJ302F	2	S1	300	300			1.0	25A	1.7	1500	300	200J	AEI
SJ401F	2	S1	400	400			.70	25A	1.7	500	400	120J	AEI
SJ402F	2	S1	400	400			1.0	25A	1.7	1500	400	200J	AEI
SJ501F	2	S1	500	500			.70	25A	1.7	500	500	120J	AEI
SJ601F	2	S1	600	600			.70	25A	1.7	500	600	120J	AEI
T1	2,3	S1	250	100	130A	1.2	130	100C	.60	10ma∅	250	125C	SOIF-6
T2	2,3	S1	500	200	130A	1.2	130	100C	.60	10ma∅	500	125C	SOIF-6
T3	2,3	S1	750	300	130A	1.2	130	100C	.60	10ma∅	750	125C	SOIF-6
T4	2,3	S1	1000	400	130A	1.2	110	100C	.60	10ma∅	1000	125C	SOIF-6
B443	2	S1	50				12	150	1.2	2000	50	150	BEN
B444	2	S1	100				12	150	1.2	2000	100	150	BEN
B445	2	S1	200				12	150	1.2	2000	200	150	BEN
B446	2	S1	300				12	150	1.2	2000	300	150	BEN
B447	2	S1	400				12	150	1.2	2000	400	150	BEN
B448	2	S1	500				12	150	1.2	2000	500	150	BEN
B449	2	S1	600				12	150	1.2	2000	600	150	BEN
CEC2383	1,2	S1	6000	6000	100	8.0	.05	100		10	6000	25	COL
CEC2384	1,2	S1	8000	8000	100	10	.05	100		10	8000	25	COL
CEC2385	1,2	S1	10K	10K	100	12	.05	100		10	10K	25	COL
D15A	1,2,3	S1	125	100	500	1.2	.50	25A	.60	1.0	100	25A	SOIF
D25C	2,3	S1	250	200	500	1.2	.50	25A	.60	150∅	200	125A	SOIF
D45C	2,3	S1	500	400	500	1.2	.50	25A	.60	150∅	400	125A	SOIF
D65C	2,3	S1	750	600	500	1.2	.50	25A	.60	150∅	600	125A	SOIF
E750C50S1	8	S1	2250	450			.05	50A		4.0		120J	AEG
FD300	1	Si	150	125	200	1.0				3.0	125	150	FSC
Ge100F	2,#	Ge	300	160			100	35A	.25	70ma		65J	AEG
OY101	TV,#	Si	700	220			.50	50A		800		140J	AEG
P8H	2,3	S1	1000	800	6000	1.2	4.0	125C	.60	3000∅	800	125C	SOIF-6
P1006	2,3	S1	125	100	6000	1.2	6.0	125C	.60	3000∅	100	125C	SOIF-6
P1010	2,3	S1	125	100	10A	1.1	10	125C	.60	3000∅	100	125C	SOIF-6
P2006	2,3	S1	250	200	6000	1.2	6.0	125C	.60	3000∅	200	125C	SOIF-6
P2010	2,3	S1	250	200	10A	1.1	10	125C	.60	3000∅	200	125C	SOIF-6
P4006	2,3	S1	500	400	6000	1.2	6.0	125C	.60	3000∅	400	125C	SOIF-6
P4010	2,3	S1	500	400	10A	1.1	10	125C	.60	3000∅	400	125C	SOIF-6

New Products

Heat Radiator



New Birtcher 4AL series heat radiators are specially designed for high-powered transistors and diodes where 50, 100, 200 and higher wattage dissipation is required. Radiators also function as a chassis in which transistors or diodes can be mounted on one side and components on the other. Width is 4½-in., lengths available in ½-in. increments to 12-ft. The mounting area on both sides is 1.44-in. x 0.156-in. thick; height is 1.03-in.

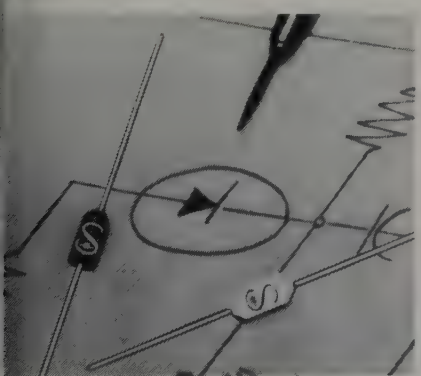
Circle 100 on Reader Service Card

Ultra High Purity Indium

Indium 99.999+% pure to meet the critical requirements of semiconductor device manufacturers is now available from Alpha Metals, Inc. This semiconductor grade indium contains less than 1 part in each million of either silver or copper. Tin and lead content is less than 3 parts per million each. Other elements are not detected by spectrographic analysis. The indium is available in bars or special shapes.

Circle 105 on Reader Service Card

Plastic, Ceramic Diodes



Two new miniature silicon rectifiers designed for critical applications in the entertainment and general industrial fields, have been introduced by Standard Rectifier Corporation. Available in plastic (7MP) and ceramic (7MH) packages, the units weigh less than 0.75 grams and measure ⅜ by .200 inches in diameter. The diodes are conservatively rated at 750 ma average rectifier current and 50-600 PIV. Operating ambient temperature is from −65° to +100° for the plastic unit and −65° to +150° for the ceramic units.

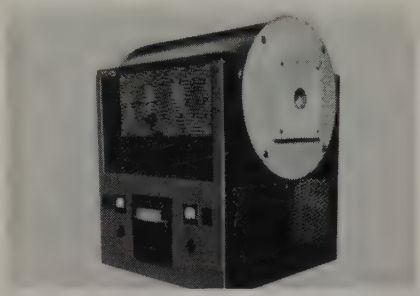
Circle 101 on Reader Service Card

Silicon Controlled Rectifiers

General Electric Company has introduced a complete new line of high current silicon controlled rectifiers. The three junction semiconductor devices are available in eight models which differ by repetitive peak reverse voltage ratings ranging from 25 to 400 volts. Average forward current rating of the C50's is up to 70 amperes maximum *a-c* rating and 110 amperes maximum *d-c* rating. The typical gate current required to fire these units is 15 milliamperes at 1.5 volts, while the maximum gate voltage to fire is 3.0 volts.

Circle 112 on Reader Service Card

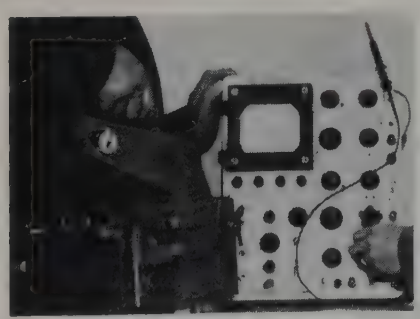
New Furnace



An electric combustion tube furnace incorporating a new type of power control was announced recently by Despatch Oven Company. Model SC-32 produces 2600°F. max., provides a twelve-inch uniform heat zone in a 2½-inch o.d. ceramic tube, and is rated at 7 kw on 220/1/60 vac. The new power control, called Thermionik Power System, is usable with any *d-c* producing or proportioning slide wire control system, or may be operated manually.

Circle 103 on Reader Service Card

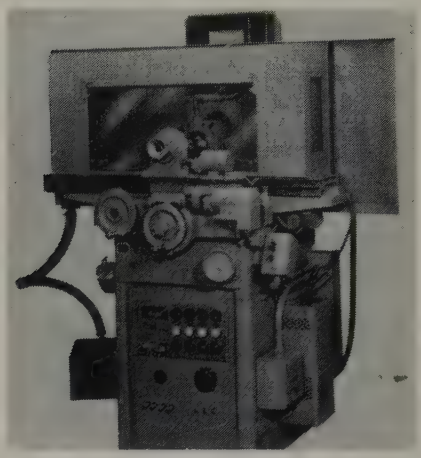
Scope Camera



The new Tektronix C-12 Oscilloscope Camera accepts Polaroid or any conventional film. It utilizes a sliding back (adjustable to horizontal or vertical) on which you can interchange the par-focal, film-holding backs, lock them securely in 5 detent positions, also rotate them thru 90° increments (with the long axis of the film horizontal or vertical). Highly adaptable, the Camera accepts a wide range of available accessories, enabling it to photograph almost any type of trace-recording application.

Circle 127 on Reader Service Card

Semiconductor Slicing Machine



Reid Brothers, Inc., has developed a new automatic machine for slicing silicon or germanium wafers. Model 612 was designed and built to answer the needs of the semiconductor industry. The application of the Post PW-4 Decitron Counter controls the repeatability accuracy of the cross feed index to within ±.0001". The table, driven by a 2 speed *d-c* Motor, is controlled by full wave rectified *a-c* with *d-c* ripples filtered through an *l-c* circuit. *A-C* Power is regulated with the Voltage Regulator Transformer assuring uniform motion of the table.

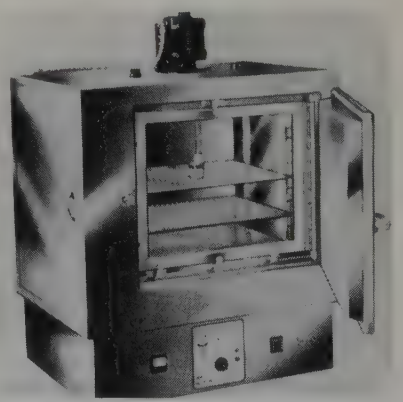
Circle 104 on Reader Service Card

Silicone Varnish

A new Class H varnish, 981, that cures at 150°C in just six hours has been announced by Dow Corning Corporation. The new material is as easy to process as most Class A and Class B varnishes, thus eliminating the need for high-temperature curing ovens in producing Class H electrical equipment. This new dipping and impregnating varnish meets AIEE requirements for both 180°C and 220°C systems.

Circle 111 on Reader Service Card

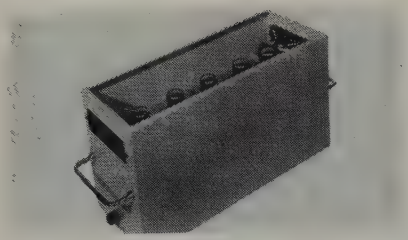
Temperature and Humidity Cabinets



Blue M Electric all stainless steel cabinets will operate to maintain between 90-99% relative humidity from room temperature to 85°C. Moreover, certain tests requiring temperatures below normal ambient, or at least below seasonably high ambient, can easily be conducted by circulation of suitable tap water through baffle cooling coil. Minimum possible temperatures are in relation to temperature of available tap water.

Circle 121 on Reader Service Card

Switching Module



A new self-contained switching module that greatly reduces the cost of life testing semiconducter diodes and rectifiers was announced by Wallson Associates, Inc. Designated Model 180, these modular life test power supplies incorporate the principles of simulator testing as opposed to brute force testing. Each is capable of switching 20 amperes average *d-c* at up to 1500 PIV. Modules may be combined to provide life test facility for many rectifiers.

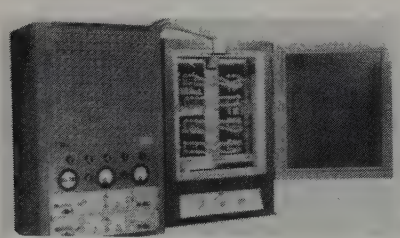
Circle 113 on Reader Service Card

Portable Control Center

Wheelco Div. of Barber-Colman Company has developed a Control Center for use in semiconductor work which is made up of laboratory and production procedures. Designed for a company requiring control equipment for use with the various single and two zone tubular type electrical furnace involved in a semiconductor program, this Control Center incorporates an 8000 Series Multipoint Recorder, a Model 407 Capacitrol and a Model 72000-S279 Chronotrol along with the necessary Magnetic Amplifiers and Saturable Reactors.

Circle 128 on Reader Service Card

Transistor Life Test System



Tenco Electronics' new transistor life test system features individual collector current controls for up to 220 transistors undergoing oven life testing. Other functions include monitoring and control of collector voltage and monitoring of elapsed time and oven temperature. The test system is basically a versatile transistor production line control console that is directly compatible with any desired testing oven over a wide temperature range of 25 to 150°C ±1°C.

Circle 115 on Reader Service Card

Vacuum Oven

An improved vacuum oven with foot operated, electric three-way valve simplifies vacuum and gas flush operation. Double doors permit pass through of workload for dry box applications. Model 733-M is one of a new series of vacuum ovens by Electric Hotpack. Chamber is capable of evacuating down to 1 micron. Controls include an accurate controlling thermostat, with pilot light, wattage selector switch, mercury thermometer and vacuum gauge calibrated from 0 to 30". All chamber walls are insulated with a three-inch blanket of precompressed glass wool. Modifications can be made for specific requirements.

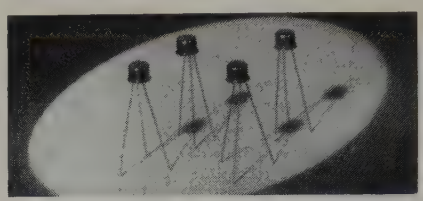
Circle 125 on Reader Service Card

Cadmium Sulfide Photocell

A new cadmium sulfide photocell with high sensitivity and high dark resistance has been developed by the JEM Electronics Division of The Pioneer Electric & Research Corporation. Said to be ideally suited for applications where either a gas phototube or a photo-multiplier tube has been used, the new photocell, CDS-9, has a resistance of over 1 megohm in darkness and has a broad response to visible light. It is non-polar and may be used on *a-c* or *d-c*. Power dissipation rating is ½ watt continuous, 2 watts for 1 minute.

Circle 117 on Reader Service Card

Mil-Qualified Transistors



USN 2N497, USN 2N498, USN 2N656 and USN 2N657, all per MIL-T-19500/74, have been added to the Rheem line of mil-qualified silicon mesa transistors. These are for general purpose, medium power, fast-switching applications and feature mesa reliability. They provide: low input impedance, low collector capacitance—typically 14 $\mu\mu$f, wide operating range—from 10μA to 500 mA, and 4 watt power dissipation. All units are stabilized before testing by 300°C storage for 72 hours and by three temperature cycles from −65°C to +200°C.

Circle 102 on Reader Service Card

Micro-Diode

A microminiaturized silicon diode designed specifically as a computer core driver was announced by Pacific Semiconductors, Inc. The new PSI type PD400 core driver Micro-Diode at 25°C is characterized by a stored charge of 25$\mu\mu$C/mA; forward voltage drop of 1.5 volts at one half ampere, and 6μsec recovery time. These characteristics, coupled with the micro configuration of the device permit the design of optimized computer memory circuitry.

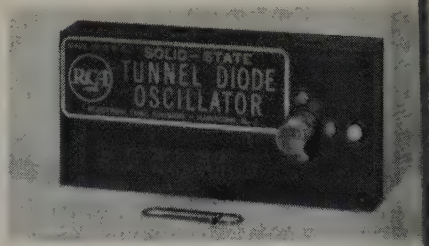
Circle 110 on Reader Service Card

Sonic Energy Cleaners

Lawrence Manufacturing Corporation Ultracleaner line of sonic energy cleaners has been broadened to include five new sizes with tank capacities up to 10 gallons for complete industrial cleaning needs. The rugged construction of this new equipment allows for continuous use in mass production cleaning as well as single operation soil-removal from electronic, mechanical, optical and horological parts and assemblies. A wide variety of cleaning agents is available, as well as immersion heaters for increased efficiency.

Circle 107 on Reader Service Card

Tunnel-Diode Oscillators



Two new, stable microwave oscillators utilizing tunnel diodes in specially designed circuits are now available from RCA. Compact and lightweight, these are complete packages ready to use as signal sources, local oscillators, etc., in applications where small size and long life are required. The SS-100 is mechanically tuned over its 1050-1400 Mc range. The center frequency of the SS-104 is specified by the user in the range 800-1400 Mc. It can be electronically tuned over a total range of 5% of its center frequency by varying the *d-c* input voltage. Both oscillators require only 0.2 volt *d-c* to produce several tenths of a milliwatt power output over their tuning ranges.

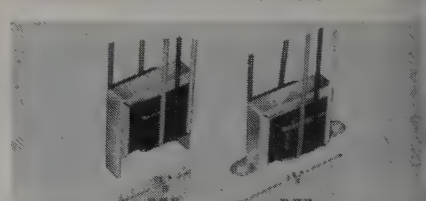
Circle 124 on Reader Service Card

Silicon Cartridge Rectifiers

Two new series High Voltage Silicon Cartridge Rectifiers, have been announced by Sarkes Tarzian, Inc. Operating temperatures range from −55°C to 150°C ambient. The units also feature low voltage drop and low reverse current. The Ferrule Mounted series (S-5490 thru S-5507) have maximum rectified *d-c* output currents varying from 45 to 100 milliamperes, and peak inverse voltage ranging from 1500 to 16,000 volts. Axial Lead series (S-5518 thru S-5535) peak inverse voltage starts at 1000 volts up to 10,000 volts, with maximum RMS input voltage ranging from 420 to 7,000 volts. Maximum average rectifying currents at 25°C vary from 75 to 250 MA, and at 100°C, from 25 to 100 MA.

Circle 122 on Reader Service Card

Transistor Audio Transformers



Nine new transistor audio transformers are now available from Chicago Standard Transformer Corporation. TA-53 is a miniature interstage transformer with a primary impedance of 5,000 ohms CT and a secondary impedance of 45,000 ohms. TA-54 is also an interstage unit with a primary impedance of 20,000 ohms and a secondary impedance of 800 ohms CT. Both units are rated at .15 watts. TA-52, an interstage transformer with both primary and secondary impedance of 500 ohms CT, and TA-55, an input transformer with a primary impedance of 500,000 ohms and a secondary impedance of 200 ohms CT, are miniature units rated at .3 watt. The other five units are designed for higher power driver and output applications and range in rating from .5 to 10 watts.

Circle 114 on Reader Service Card

(Continued on page 64)

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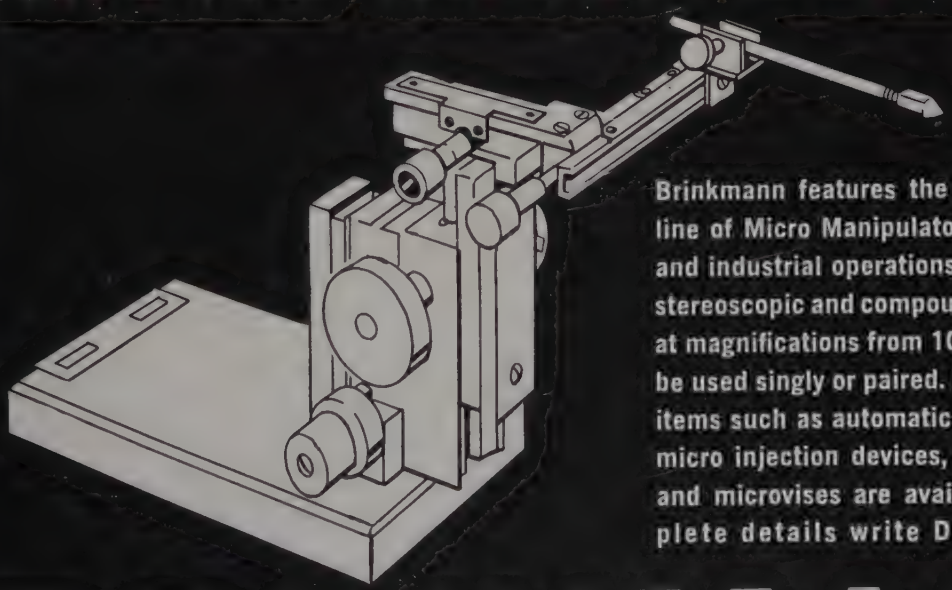
Circle No. 29 on Reader Service Card

MICRO MANIPULATORS



Brinkmann features the most complete line of Micro Manipulators for scientific and industrial operations. Available with stereoscopic and compound microscopes at magnifications from 10 to 1000 x. Can be used singly or paired. Many accessory items such as automatic pipette pullers, micro injection devices, pipette holders and microvises are available. For complete details write Department M.

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Need man with 2 or more years experience in Device Development on silicon transistors or diodes for major semiconductor manufacturer.

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Major semiconductor manufacturer seeks man with 3 or more years experience on diffusion techniques to step into project management position. Prefer pilot production experience and ability to work out all process problems. An exceptional opportunity for rapid advancement.

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Industry

CONFERENCE CALENDAR

The Following March 1961 Meetings Are Scheduled

March 2-4 Optical Society of America, Pick-Roosevelt Hotel, Pittsburgh, Pa. Sponsored by American Institute of Physics.

March 15-17 Spring Conference EIA, Statler Hilton Hotel, Washington, D. C.

March 20-23 IRE International Convention, Coliseum & Waldorf Astoria Hotel, NYC. Sponsored by all PG's. For Information: Dr. G. K. Teal, IRE, 1 E. 79th St., N. Y. 21, N. Y.

March 20-22 American Physical Society, Monterey, Calif.

March 20-24 12th Western Metal Congress & Exposition, Pan-Pacific Auditorium & Ambassador Hotel, Los Angeles. Sponsored by American Society for Metals. For Information: Allan R. Putnam, ASM, Metals Park (Novelty), Ohio.

March 21-30 American Chemical Society 139th National Meeting, St. Louis, Mo.

March 21-23 23rd Annual American Power Conference, Sherman Hotel, Chicago. Sponsored by 6 professional societies.

March 27-31 3rd Symposium on Temperature—Its Measurement and Control in Science and Industry. Veteran's Memorial Hall & Deshler-Hilton Hotel, Columbus, Ohio. Sponsored by AIP, ISA and Nat'l Bureau of Standards. For Information: V. W. Sikora, Instrument Soc. of America, 313 Sixth Ave., Pittsburgh 22, Pa.

Charles F. Booher, vice president of The Birtcher Corporation/Industrial Division, has been granted patent No. 2,958,515 for 17 claims on semiconductor heat radiators. The patent has been assigned to The Birtcher Corporation, and covers some 80-odd fin-type radiators designed to increase transistor and diode efficiency and to prevent thermal breakdown (thermal runaway).

The American Association for the Advancement of Science (AAAS) announced recently that it has presented its annual "Industrial Science Achievement Award" to Bell Telephone Laboratories, Incorporated. The citation was for achievements in the field of universal communication during the year 1960.

An Infrared Thermometry school for industrial instrumentation personnel has been established by Radiation

News . . .

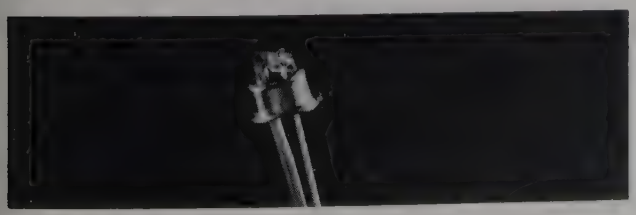
lectronics Company, a division of Comptometer Corp. he two-day course is conducted by Herbert L. Berman id Dr. Arthur E. Goldberg of the company. Lectures ver: principles and applications of infrared sources, in-ared sensing devices, optical materials, radiation ther-ometers, and remote temperature measurement and ntrol. Laboratory sessions are devoted to: emissivity, ass and flame temperatures, thermal scanning, and tem-erature control. Courses of the Infrared Thermometry chool are scheduled regularly at monthly intervals. In-uiries should be addressed to: R. Van Scoyoc, Radiation lectronics Co., 5600 Jarvis Avenue, Chicago 48, Illinois.

The Electrada Corporation recently announced plans or a new "Photo-Optronic Laboratory," which will be ne of the first commercial undertakings to study the ature of light in its application to electronics and chem-stry. The new laboratory will be equipped to perform ery precise measurements of the physical and chemical ffects of light, such as the speed and resolution of film mulsions and other light-sensitive coatings, within the icrosecond-micron range. In addition, special devices ill be installed to study the effects of light on crystals nd photoconductors. The Laboratory's services will be ade available to industry and the government on a con-act basis. It will be located at 11244 Playa Street, Culver ity, Calif.

Circle No. 32 on Reader Service Card

RESEARCH & DEVELOPMENT

Philco Corporation announced recently that a major upgrading in the reliability of medium frequency silicon transistors has been achieved with a new production process which has made possible the development of the Silicon Precision Alloy Transistor (SPAT). H. K. Ishler, director of semiconductor operations at the firm's Lansdale Division, explained that the new SPAT p-n-p silicon transistors are produced by a strip alloy technique which "permits an accurate measurement of the diode voltage and beta of every SPAT transistor during the manufacturing process." In the strip alloying process, each transistor is indexed on a precision carrier which guides the device into a minified alloying furnace and positions it in perfect alignment with the heat source. In this manner every transistor is heat-treated identically. Fabrication of these transistors has not necessitated usage of any new or different materials, nor has there been any need for device design changes which otherwise might have affected behavior of the units on extended life, according to the company.



An omegatron mass spectrometer for use as a relatively inexpensive and automatic scanning analyzer has been developed by Raytheon to detect and measure impurities in high vacuum. An investigation of the interaction of oxygen with atomically clean germanium and silicon surfaces (performed with a very sensitive quartz microbalance housed in an ultra-high vacuum system) led to development of the new "tool." The studies referred to necessitated rigorous conditions of cleanliness and the omegatron spectrometer was developed to provide a continuous analysis of the gaseous ambient. A complete investigation of residual gases in electron tube and other high vacuum systems involves a knowledge of the origin of the contaminants; the partial pressure of each gas; the physical state of the species, i.e., atomic, molecular, ionic; and the nature of their interaction with system components and walls. In an electron tube where there are hot filaments, potentials of varying magnitudes, and a variety of glass and metal components—all these factors must be known in order to understand the effect of the residual gases upon tube parameters and life. The apparatus used consisted of a small volume radio-frequency mass spectrometer operating on a cyclotron resonance principle—the omegatron; a very sensitive quartz microbalance with which weight changes of 10 minus 7 grams were detected; a system employing a modified Wagener technique to study getter activity; and finally, associated vacuum systems using oil, mercury, ion or cryogenic pumping. Pressures of 10 minus 10 mm. were obtained.

acceptance won...
growing preference...
reasons why...

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No trace of arsenics
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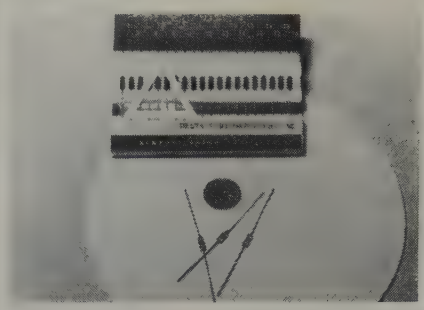
Circle No. 34 on Reader Service Card

New Products

(From page 60)

Computer-Rectifier Diodes



Delta Semiconductors announces a new series of all purpose glass silicon computer-rectifier diodes that combine 400 ma forward conductance at 1V, 30 nanosecond recovery measured on a sampling oscilloscope and .025 μa reverse leakage current. Designated the DW series, individual numbers are available with peak inverse voltages from 40V to 275V. They feature a special alloy-diffused junction that combines low reverse leakage current with high forward conductance. Glass package has a 600 mw heat sink for greatest heat dissipation.

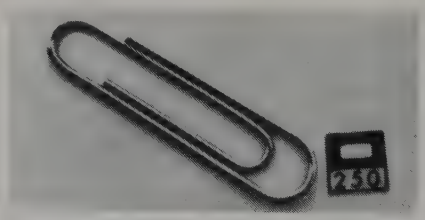
Circle 109 on Reader Service Card

Power Supplies

The Electronic Measurements Company line of Regatran Semiconductor *D-C* Power Supplies now includes a new zero-to-50 volt, fully programmable series, entitled Series TP. These power supplies feature continuously variable current-limiting, line or load regulation of 0.1% or 0.01 volt, and rms ripple of less than 1 millivolt. The series is offered in three models rated at 0.5, 1, and 3 amperes respectively. Metering and terminal arrangements are optional.

Circle 106 on Reader Service Card

Temperature Indicating Label



Pyrodyne, Inc. announces its new miniature temperature indicating label, Model 200 Temp-Plate. Measuring only ¼" square, overall size, it is useful for instrumenting transistors and other miniature electronic components. The tiny plastic adhesive tab that sticks on almost any surface turns black when its temperature reaches any desired value between 100° and 500°F. Its accuracy is ±1%.

Circle 120 on Reader Service Card

Silicon Rectifiers

Stud-mounted rectifiers capable of delivering up to 20 amperes at 150°C in half-wave circuits have been announced by Trans-Sil Corporation. The double-diffused silicon junction units, designed for power rectifier and magamp applications, are designed as Series MO. The peak inverse voltage capability of rectifiers in this series is from 50 to 800 PIV. In full wave circuits, currents up to 60 amperes can be obtained.

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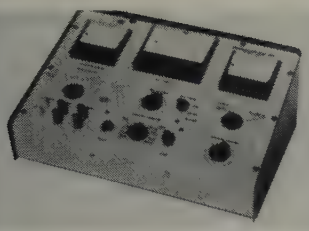
WE CATALOG IN eem electronic engineers master Sec. 2900

Circle No. 51 on Reader Service Card

ransistor Tester



Accurate testing of *n-p-n* and *p-n-p* ransistors is made rapid and simple by ne Armour Stablvolt Transistor Tester lodel T-340. Ideal for incoming inspec- ion and production line testing, the new nstrument measures the four basic pa- ameters necessary to check a transistor's erformance. Power requirements to the ntegral power supply are 115V, 60 cycles. No special connections or time con- uming adjustments are required; tran- istors are simply plugged into the unit nd each test made by positioning the unction switch. Results are read directly rom a meter. Parallel test receptacles ermit testing of transistors in circuits r environmental chambers.

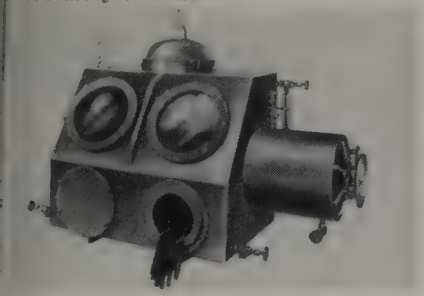
Circle 118 on Reader Service Card

RF Diodes

A series of six subminiature silicon oint-contact diodes with all-glass con- truction, and designed for convenient se in miniature RF circuitry is avail- able from Microwave Associates, Inc. All-glass construction in these diodes (1N830 through 1N833 series) assures a very reliable hermetic seal, enables direct soldering to axial leads close to the diode shell, and also reduces shunt capacitance for improved RF bandwidth at microwave frequencies.

Circle 126 on Reader Service Card

Laboratory Enclosure



Chemical and metallurgical research on materials under high vacuum as well as work with radioisotopes and poisonous substances in a controlled atmosphere are facilitated by a new type of laboratory enclosure announced by S. Blickman, Inc. They are available in standard units of 3' and 4' modules and also in any size required. Vacuum dry boxes have been tested with a mechanical pump and have been pumped down to approximately 50 microns.

Circle 116 on Reader Service Card

Component Clip

A new "no-twist" clip has been added to the Atlee Corporation's product line. Designed specifically for use in cases where a single attachment point is required, integral projections on the bottom of this clip eliminate twisting. The clip meets all the requirements of holding components against shock and vibration. Their holding power increases as shock and vibration increase, measured by the force required to remove the component.

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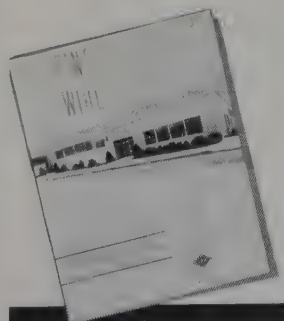

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AVNET•2728 N. Mannheim Rd., Melrose Park, Ill.- GL 5-8160

Circle 37 on Reader Service Card

Wet Test Meter

A new Wet Test Meter for the precise measurement of Gas Flow is announced by the Precision Scientific Company. Accurate to within ±½ of 1% of volume, these new meters feature a cast aluminum housing with an epoxy-resin plated interior to withstand corrosive effects of acid-laden gases. Operable pressure range is from 0.018 PSI to 15 PSI. Available in 20 cubic feet per hour and also 680 liter per hour models.

Circle 119 on Reader Service Card

The Sprague Electric Company has begun production of small-signal silicon transistors to supplement the germanium transistors which they have been manufacturing for highspeed switching applications in digital computers and for use in high-frequency communication equipment. "The transistors are being made under license from the Philco Corp. and will be electrically and mechanically interchangeable with Philco types bearing the same part numbers giving the electronics industry a second source for precision-etch surface-alloy silicon transistors," the company stated. Initial transistors to enter production include Types 2N1118, 2N1118A, 2N1119, and 2N1429. These high-frequency devices feature typically high f_t, low collector saturation voltage, and low saturation drop, allowing the design of medium-speed switching circuits with excellent control of output levels over the temperature range of —65 C to +140 C. They are also well-suited for direct-coupled logic circuits in computers.

Circle 131 on Reader Service Card

Tyco Semiconductor Corporation recently announced the availability of a new series of 6 gallium arsenide varactor diodes. The AP-1 series range in cut off frequencies from 60 to 150 KMC minimum at an operating bias of —2 volts measured at 10 KMC, and are packaged in a conventional double ended metal/ceramic microwave diode cartridge. The series has a (cw) power dissipation rating of 150 mw at 25°C measured at 10 KMC and a breakdown voltage rating of 6 volts for a reverse current of 10 ua at this temperature.

Circle 132 on Reader Service Card

Semiconductor Technology

Scully-Anthony Corp., makes available enclosures and help in sealing enclosures with their cool "KOLDWELD" process. Also provided is a process engineering service for pre-sealing preparation which will protect the vital elements of the device, and licensing for all processing and tooling. Enclosures are made from the suitably malleable metals, copper or aluminum, both highly desirable because of excellent heat conductivity. Copper surfaces are pretreated to fit particularized processes. Direct-bond feed-throughs of glass can be furnished for either enclosure base metal.

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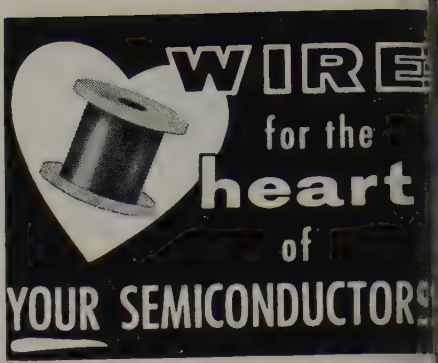

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Circle 38 on Reader Service Card

Device Applications

Two new transistor-regulated power supplies for use in lightweight, miniaturized equipment have been developed by the Hycon Mfg. Company of Pasadena, California. Only silicon semiconductors are used to offer better reliability at higher ambient temperatures.

Robotomics, Inc., Phoenix, Ariz., announces an alpha-numeric display featuring a completely transistorized built-in memory.

Gertsch Products, 3211 So. Cienega Blvd., Los Angeles, Calif., announces a line of small-size, fully transistorized, case-sensitive null indicators.

Pacific Telemetry Systems, Culver City, Calif., announces the development of a new miniaturized carrier-amplifier system for use with low level output transducers. This system features all solid-state modular construction.

Magnetic Research Corporation, Hawthorne, Calif., has announced a new solid state *d-c* to *a-c* inverter, first in a new line of lightweight compact inverters for air and space vehicle applications. The power-conversion circuit uses power transistors as electronically controlled switches.

R S Electronics Corp., Palo Alto, Calif., has announced a miniaturized command receiver for missile flight guidance and safety operations. The command function is performed by a transistorized receiver and a complementary decoder unit, each housed in a cast aluminum case.

A new, all-transistor stereo preamplifier-amplifier unit has been developed by Polar Electronics, Ltd., 1514 Oak Street, South Pasadena, California. Because of its all-transistor construction, the unit has no heat, hum or microphonic problem.

Syracuse Electronics Corp., Syracuse, N. Y., has developed a transistorized timer as a direct replacement for all thermal delays.

Tuning Fork Standards, Inc., 206 N. Wells St., Chicago, has announced a transistorized tuning fork oscillator. The output signal in the FSI oscillator can be greater than 1 volts RMS, sine wave or square wave, across a 10K load and can also include transistorized frequency dividers.

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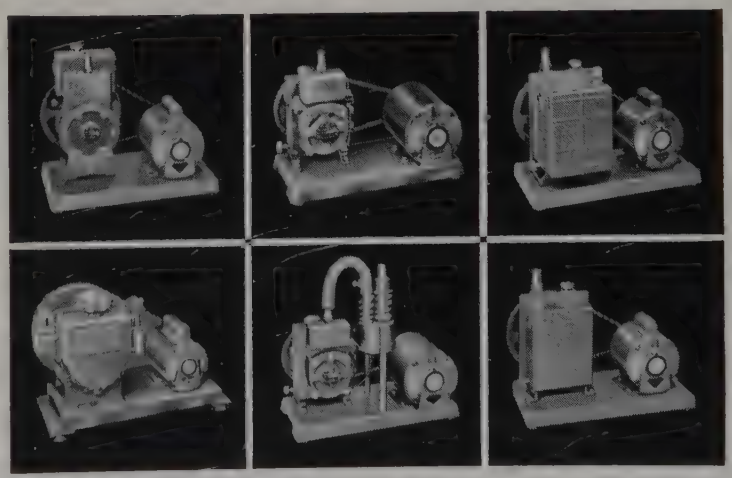

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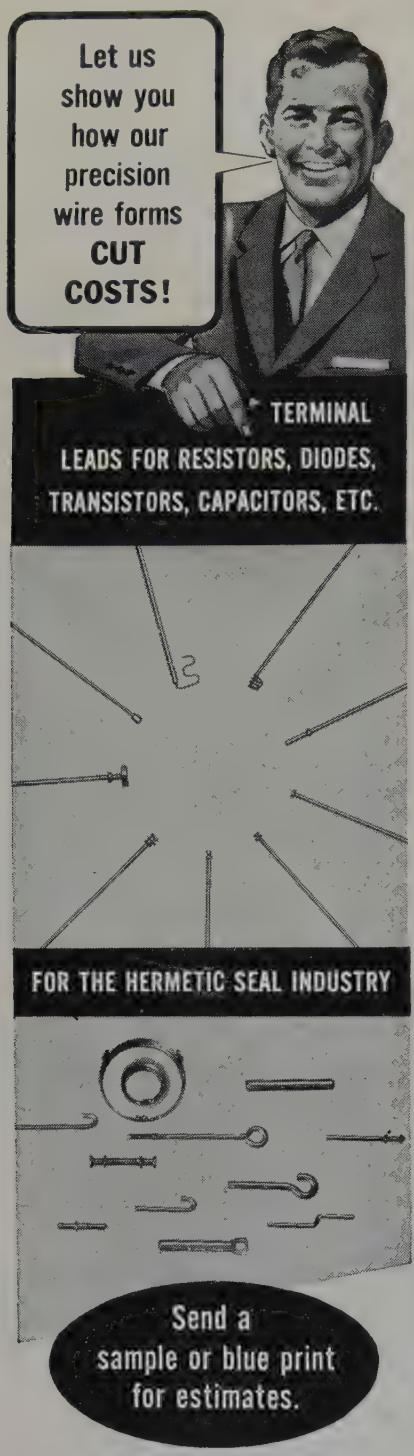
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New Literature

Pyrofuze Corp., an affiliate of Sigmund Cohn Corp., has issued a new brochure on Pyrofuze. This exothermic fuze material has been manufactured for the explosives and ignition fields and has already applied to a broad range of components. Generally employed in wire form, it is also available as ribbon, sheet and in pellet shapes. The wire itself is offered in the size range approximately .040 inch diameter to sizes smaller than a human hair.

Circle 150 on Reader Service Card

Written in catalog style, a new 16-page booklet gives a detailed presentation of the seven available Tektronix oscilloscopes with 3-inch cathode-ray tubes, including the rack-mount models. The booklet contains complete specifications, performance characteristics, pertinent illustrations, for all seven instruments.

Circle 151 on Reader Service Card

Air-Vac Engineering Company announces the availability of their new Bulletin on their Bazooka Vacuum Probe and Transducer. Bulletin tells how production operators now can pick up and handle miniature parts of all shapes and materials rapidly with this Vacuum Probe, which has a finger-operated shut-off valve for releasing parts from Probe Tip.

Circle 152 on Reader Service Card

Nine automatic machines for high production product finishing are illustrated and described in a brochure made available by Conforming Matrix Corporation. These machines permit production increases of hundreds to one over hand methods of decoration of products of all sizes and description.

Circle 153 on Reader Service Card

A four-page brochure entitled, "Single Crystal Materials for Solid State Electronics" is now available from Solid State Materials Corporation. This brochure shows many of the company's Research, Development, and Production facilities. Among the crystals produced are: Intermetallic Compounds, Silicon, Germanium, Paramagnetics, Ferromagnetics, and Ferroelectrics.

Circle 154 on Reader Service Card

Technical data bulletin Z-105, describing Alloy D-800, a new high-strength low-temperature solder alloy, is now available from Accurate Specialties Co., Inc. The bulletin describes the alloy's suitability for semiconductor processing as a lead base "*N*" type ohmic junction material, containing neither boron nor free iron. Lists data such as specific gravity, specific weight, compressive strength, fatigue strength, and tensile strengths and hardness at various temperatures.

Circle 155 on Reader Service Card

A new bulletin describing Acoustica's 40-KC line of ultrasonic cleaning systems is available from the company's Marketing Department.

Circle 157 on Reader Service Card

(*Continued on next page*)

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diodes
rectifiers
test all your
semiconductors
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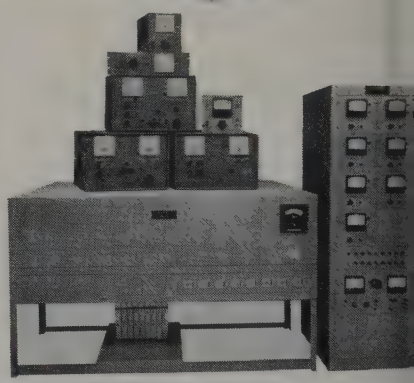

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Circle No. 41 on Reader Service Card

ll-new bulletin made available by solidated Reactive Metals, Inc., con- s data on fine wire for semiconduc- , thermocouples, and other electronic lications. In addition to furnishing plete data on this firm's many prod- s in the electronic field, the technical letin contains a useful, authoritative rt on "Fine Wire Applications, Com- itions and Pertinent Properties."

Circle 156 on Reader Service Card

Bulletin 121 describing the new HT-1 ies of high heat and wear resistant amics is now available from Duramic ducts, Inc. Applications are listed as ll as complete data on the 3 basic es available. Includes information such specific gravity, softening temperature, dness, thermal expansion coefficient, sile strength, compressive strength, lectric constant, power factor, and rmal conductivity.

Circle 158 on Reader Service Card

Evaporation Sources For Metals—Tech- cal Bulletin Number 102 gives a com- te list of the more commonly used tals for the deposition of thin or thick n in Hi Vacuum. Includes the metal's lting temperature (C°), recommended aporation source and general configu- ion. This Technical Bulletin is a com- ndium of various technical publica- ns, and Allen-Jones, Inc. experience in Hi Vacuum field.

Circle 160 on Reader Service Card

Engineering data concerning basic test rameters for silicon or germanium *p-n* and *p-n-p* transistors, and specifi- ions of their Model T-340 Transistor ster have just been published by the rmour Stablvolt division of Magnetic search Corporation. The new data eet contains complete details and speci- ations including applications, opera- on and design.

Circle 161 on Reader Service Card

Ferrotran Electronics Co., Inc. has an- unced the publication of their 1961 cat- og which includes their complete line semiconductor, solid state power sup- ies, redesigned line of I-F and audio nplifiers and the latest types of solid ate rectifier transformers. The catalog so includes descriptions of special de- ces such as a recorder amplifier, tele- one amplifier repeater coils, and RF etectors and Tuners.

Circle 162 on Reader Service Card

A new descriptive specification and ata sheet, published by the Wilson Rub- er Co., supplies vital information on the ompany's new Wil-Gard Interchangeable Berkeley Box" Sleeve and Glove com- ination. Versatility, economy, safety, and ncreased performance range typify this ew glove-sleeve combination as one of he most advanced innovations in dry ox applications.

Circle 163 on Reader Service Card

Technical data and information on new Sildisc" silicon diodes for printed circuit pplications is available from the Elec- on Division of Controls Company of merica. Separate literature is available n the company's diffused Zener diodes, ouble anode (twin Zener) diodes, and eneral purpose diodes. The various con- gurations, illustrated in the literature, ake production assembly methods pos- ble in terminal strips, plug-in, and lip-in mounting arrangements.

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Graphite Facts

by George T. Sermon, President
United Carbon Products Co.

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WILLIAM C. DIMAN,
Hayes Furnace Division Manager, explains . . .

WHY ELECTRONICS TURN TO HAYES

Extremely Close Process Control is vital in manufacturing semi-conductors and other electronic parts. Without this control, costs and scrap rates go up, product performance becomes unpredictable, and product life is drastically reduced. *The Trend Is To Hayes*—More and more electronic firms are looking to Hayes for consulting assistance and for equipment to solve complex and exacting heat treat jobs. Here are some "for instances" of the advanced equipment Hayes is offering:

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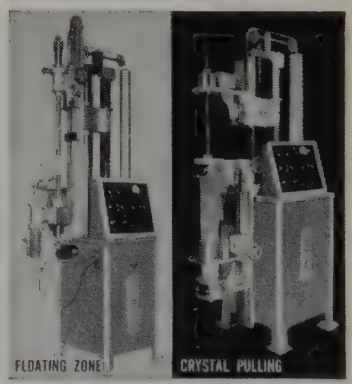

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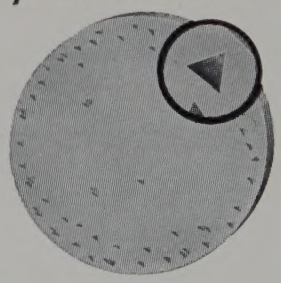

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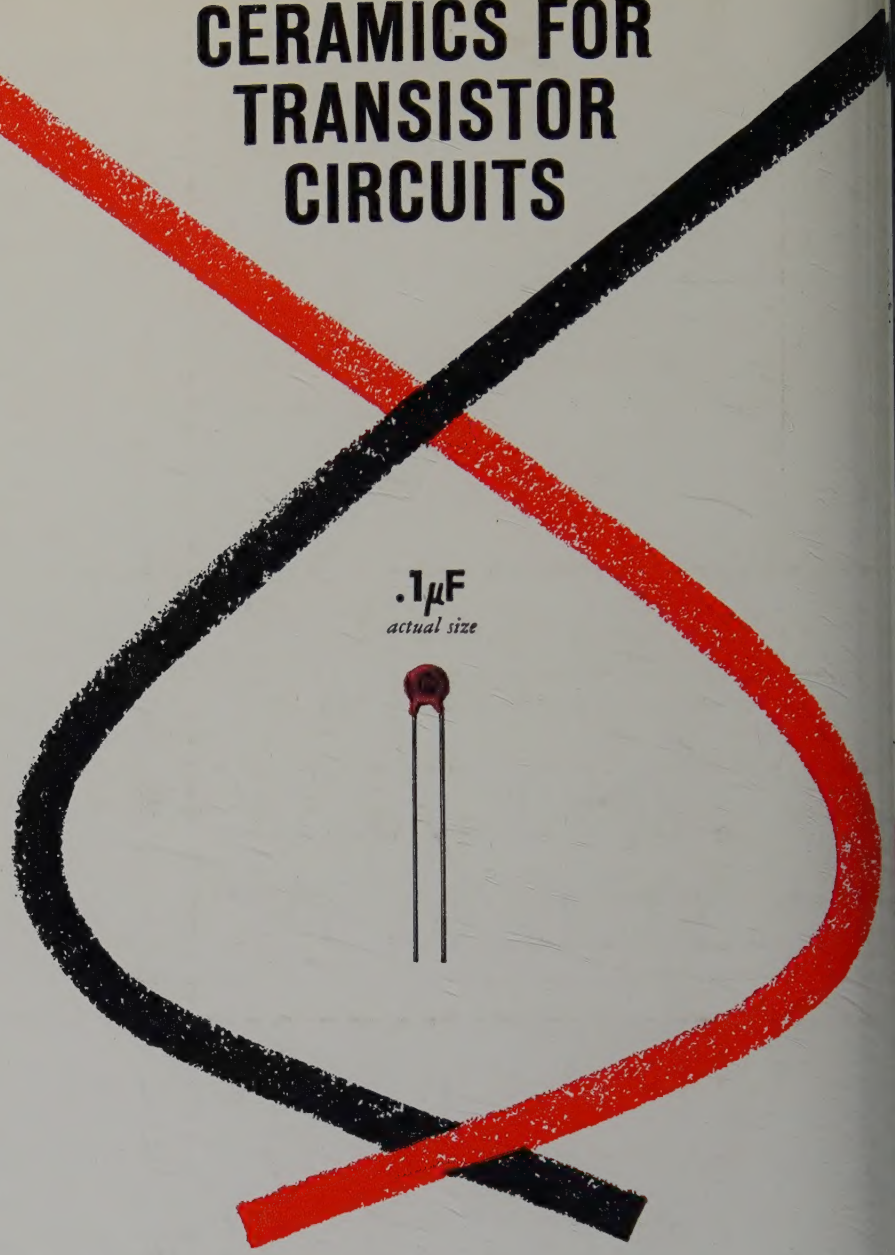

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